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STATISTICAL MODELING AND ESTIMATION OF RELIABILITY FUNCTIONS FOR SOFTWARE (SMERFS) USER'S GUIDE

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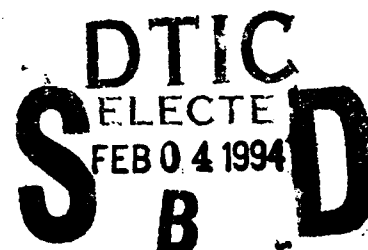Naval Surface Warfare Center
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FOREWORD

This report revises and supersedes NAVSWC TR 84-373, Revision 2, dated March 1991 (which should be discarded). The revision reflects the current Statistical Modeling and Estimation of Reliability Functions for Software (SMERFS) software package. The program has undergone many enhancements and modifications, including (1) the implementation of the new model applicability analyses, such as accuracy, bias, trend, and noise; (2) the addition of the Jelinski/Moranda De-Eutrophication model for execution time data; (3) the update to the Schneidewind model for interval data to be more consistent with his current theories; and (4) the addition of a Goodness-of-Fit routine for the execution time models.

The report has been reviewed by Dr. Richard Lorey, Head, Advanced Computation Technology Group. Comments concerning this technical report should be directed to the Commander, NSWCDD, Attn: B10, Dahlgren, Virginia 22448-5000.

Approved by:

D. B. COLBY, Head
Systems Research and Technology Department

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ABSTRACT

This is the third in a series of Naval Surface Warfare Center Dahlgren Division (NSWCDD) technical reports concerning software reliability. The first report, A Survey of Software Reliability Modeling and Estimation, NSWC TR 82-171, discusses various approaches advocated for reliability estimation; reviews various models proposed for this estimation process; provides model assumptions, estimates of reliability, and the precision of those estimates; and provides the data required for the models' implementation. Eight software reliability models were selected to form the basis of a library. This library also contains data edit, transformation, general statistics, and Goodness-of-Fit functions. The original Statistical Modeling and Estimation of Reliability Functions for Software (SMERFS) Library was described in the SMERFS Library Access Guide, NSWC TR 84-371. The enhanced library, which now contains 11 models and model applicability analyses, is explained in NSWCDD TR 84-371, Revision 3. The execution of this more powerful library, through the new SMERFS driver, is explained herein.

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CHAPTER 1

DOCUMENT OVERVIEW

1.1 INTRODUCTION

This report is designed to provide supplemental information concerning the execution of the revised Statistical Modeling and Estimation of Reliability Functions for Software (SMERFS) software package. The term "supplemental" is used because SMERFS actually contains its own user's guide. SMERFS is interactive in execution, and its processing is controlled through the user selections of various menu options and user responses to program-generated output prompts. Within certain areas, the user may even choose to let the program list the assumptions and requirements before initiating a particular portion of the program.

Because of these SMERFS design features, this report is not really a user's guide in its purest sense. Its primary purpose is to convey the processing features of SMERFS and to explain (in more detail) the generated prompts and resulting computational outputs. The contents of this report may be used to develop a master testing plan, including the determination and collection of all input requirements for the SMERFS program.

1.2 HISTORICAL BACKGROUND

The original SMERFS software package was released in 1984 and consisted of the SMERFS Library (SMFLIB) (Reference 1) and three machine-dependent drivers. The SMFLIB contained the statistical and mathematical processing required to obtain the various software reliability estimates (Reference 2). The three drivers allowed this library to be executed in an interactive mode on the Naval Surface Warfare Center Dahlgren Division (NSWCDD) Control Data Corporation (CDC) 6700, the CDC CYBER 170/760, and the VAX 11/780 computer systems. For other systems, the authors suggested creating a new driver or modifying the driver closest to the system.

In 1987, the first revision to the SMERFS software package was released. That revision primarily affected the driver and its documentation, but changes were also made to the library. Perhaps the most important modification to the library involved the discovery of an error in the implementation of the equations for the second and third treatment types of Schneidewind's Maximum Likelihood model for interval data analysis. That error was corrected in the release and cited in the first revision.

The driver for that SMERFS software package was completely machine independent; it being a subset of the American National Standards Institute (ANSI) specifications for the FORTRAN 77 compiler. To transport the program from a mainframe (e.g., the CDC 170/875 at NSWCDD) to either a minicomputer (e.g., the VAX 11/785) or any IBM-compatible Personal Computer (PC) only required changing the single precision declarations to double precision. The implicit variable declarations had to

be modified to double precision when transporting to "smaller" computer systems to yield the same "good" predictions as could be obtained on "larger" computer systems. The modification to the variable declaration line had to be performed in all routines of the driver and the library.

In addition to the feature of complete machine independence, the driver was modified in many other ways. It included two additional options. An internal line printer plotter had been added for users without access to the TEKTRONIX PLOT-10 Library or a graphics terminal. Although the graphs are crude, they can still assist the user in detecting "trends" in the data or residuals, and in determining how well the fitted model predicts the data.

The second option was the creation of a file of all program prompts, user responses, and program output over a single SMERFS execution. Upon completion of the SMERFS program, the file can be cataloged for future documentation purposes. Also, the file could be used in determining user input errors during execution.

Substantial efforts were also made to reduce the amount of generated program prompts (and therefore user responses). Several global flags were added to the driver to transfer the data type, the prediction method, and other information. That information was continually requested in the previous SMERFS release. These flags were also used to reduce the possibility of the user performing an analysis using the wrong data.

The generated output of the SMERFS software package had also undergone some cosmetic cleanup, including right-hand justification of the text, and (more importantly) the addition of lead asterisks on all error messages.

In 1990, the second revision to the SMERFS software package was released. That revision primarily affected the library and its documentation, but interface changes (caused by the new library) and general enhancements were also made to the driver.

Prior to that release, the software reliability models included in the SMFLIB used either the Nelder-Mead algorithm or the Newton-Raphson procedure. Those numerical methods, in addition to requiring initial starting values, have the inherent problem of "divergence." This is the condition in which, while attempting to converge on the optimum value of the function (if it exists), the method actually begins to move away from that maximum (minimum). The models could also encounter a possible division by zero, exponential overflow, or exponential underflow while attempting to converge on that optimum value.

The prior problems were almost completely eliminated by the use of the Dekker-Brent and Trust Region algorithms in the second revision. These optimization techniques establish most of the initial starting values, are more able to handle "misbehaving" data, and converge to the optimum value of the function more often and more readily.

Two additional models were also added to the SMFLIB, bringing the total to 10. Those were John Musa's Logarithmic Poisson Execution model (Reference 3) and Yamada's S-Shaped Reliability Growth model (Reference 4, pages 475-478).

In addition to the modifications required because of the new SMFLIB, the driver was also modified in two areas. First, the three routines used to validate the model fit were grouped under a single

secondary module. Second, an optional output file was available to overcome the "crudeness" of the SMERFS graphic utility, while retaining the achieved complete machine independence. The file, containing all (selected) data used in plot generations, could be processed (using the graphic resources available to the user) to produce plots of high quality.

In 1993, the third revision to the SMERFS software package was released (SMERFS5). This revision has equally affected the driver and the library. The changes to the SMFLIB include the addition of a Goodness-of-Fit analysis for execution time models through the Kolmogorov-Smirnov Statistic, the addition of the Jelinski/Moranda De-Eutrophication model, the addition of several model applicability analyses (Reference 5), and the alteration of the Schneidewind model to be more consistent with his current software reliability model (Reference 6).

The changes (specific) to the driver include the reduction in size of the SMERFS data file to only the number of observed elements, the addition of the units for Time-Between-Failure (TBF) data types, the input of an American Standard Code for Information Interchange (ASCII) file of data (rather than requiring the user to input the initial data via the keyboard option), and the additional standardization of model estimations and predictions (through the addition of many equations within the driver using the parameters returned from the SMFLIB). Tables 1-1 and 1-2 list the values generated for execution time data models and interval data models, respectively. The abbreviations in the column headers on those tables correspond to the software reliability models, as follows:

a. GEO - Geometric model
b. JAM - Jelinski/Moranda De-Eutrophication model
c. LAV - Littlewood and Verrall's Bayesian Reliability Growth model
d. MUS - John Musa's Basic Execution Time model
e. MSA - John Musa's Logarithmic Poisson model
f. NPT - Non-homogeneous Poisson model (for execution time)
g. BAM - Brooks and Motley's Discrete Software Reliability model
h. GPO - Generalized Poisson model
i. NPI - Non-homogeneous Poisson model (for interval data)
j. SDW - Schneidewind's Maximum Likelihood model
k. ESH - Yamada's S-Shaped Reliability Growth model

Within those tables, shaded regions indicate new or enhanced capabilities over the previous SMERFS revision, checkmarks indicate values printed by the SMERFS software package, and stars indicate values calculated in the driver portion. For example, the Mean-Time-Before-Next-Failure (MTBNF) is output for the first five (listed) models; however, the values for the third and fifth are computed in the driver.

1.3 OPERATIONAL ENVIRONMENT

The SMERFS program is currently available on a number of different computers at NSWCDD, Dahlgren, Virginia. These range from large mainframes to PCs. The transfer to other computers should require no additional modifications or alterations, simply recompilation on the new target computer. The program is constructed using only a subset of the ANSI specifications for the FORTRAN 77 compiler. A FORTRAN 77 compiler (meeting those ANSI specifications) is the only requirement for establishing the program on another computer system, in addition to the previously discussed single and double precision declarations.

TABLE 1-1. VALUES GENERATED FOR EXECUTION TIME DATA MODELS

MODEL ESTIMATES AND PREDICTIONS	GEO	JAM	LAV	MUS	MSA	NPT
ALPHA Parameter (Model Specific)			✓			
BETA0 Parameter (Model Specific)			✓		✓	
BETA1 Parameter (Model Specific)			✓		✓	
Proportionality Constant	✓	✓				✓
Hazard Rate Parameter	✓					
Initial Intensity Function	✓★	✓	✓★	✓	✓	✓★
Current Intensity Function	✓★	✓★	✓★	✓	✓	✓★
Initial MTBNF				✓		
Current MTBNF	✓	✓	✓★	✓	✓★	
Total Number of Faults		✓		✓		✓
Total Number of Faults Remaining		✓		✓★		✓★
Purification Level	✓	✓★		✓★	✓★	✓★
Expected Reliability for a Specified Time		✓★		✓★	✓★	✓
Time to Reach a Specified Reliability for a Specified Operational Time						✓
Total MTBNF for the Next K Failures	✓★	✓	✓★	✓★	✓★	
Time and Number of Failures to Reach a Desired Intensity Function	✓★	✓★	✓★	✓★	✓	✓★
Time and Number of Failures to Reach a Desired MTBNF				✓		
Number of Failures Expected in a Specified Time	✓★	✓★	✓★	✓★	✓	✓★

TABLE 1-2. VALUES GENERATED FOR INTERVAL DATA MODELS

MODEL ESTIMATES AND PREDICTIONS	BAM	GPO	NPI	SDW	ESH
ALPHA Parameter (Model Specific)		✓		✓	
BETA Parameter (Model Specific)				✓	
Proportionality Constant (Model Specific)		✓	✓		✓
Probability of Detecting Faults	✓				
Total Number of Faults	✓	✓	✓	✓	✓
Total Number of Faults Remaining	✓★	✓	-✓★	✓★	✓★
Weighted Least Squares Criteria				✓	
Mean Square Error (Faults) Criteria				✓	
Mean Square Error (Time) Criteria				✓	
Number of Faults Expected in the Next K Periods	✓	✓	✓	✓	✓
Number of Periods Needed to Discover the Next M Faults	✓★	✓★	✓★	✓	✓★
Software Reliability in Next Period					✓

As for the establishment of the program on a PC, the authors are not aware of any IBM-compatible PC on which the program executable file cannot be simply loaded and executed. SMERFS does not make use of any special hardware (e.g., a math coprocessor), special operating system features, or special peripheral support software (e.g., plotters or database managers).

1.4 USER'S GUIDE ORGANIZATION

This report is organized to provide easy access to the information necessary to perform a software reliability analysis and for the maintenance of the files of failure and fault data. The information is divided into 13 chapters. A user should be able to easily locate and examine a desired section and determine what additional data (if any) are needed and the potential errors that may occur.

Chapter 2 contains the information necessary to initiate execution of the program, including the necessary computer commands. This chapter includes the first menu of SMERFS, which conveys the

nine main modules (input, edit, unit conversion, transformation, general statistics, raw plot, the model applicability analysis, the software reliability models, and the analyses of model fit).

Chapters 3 through 11 contain the documentation on each of the eight main modules. The contents of the eighth main module (the software reliability models) are divided into two chapters (hence the extra chapter). There are actually two sets of models within SMERFS. There is a set of six models for execution time data and another set of five models for interval data. (Refer to Chapter 3 for comments on the different data types, and Chapters 10 and 11 for a list of the models.)

Chapter 12 contains the analysis of model fit processing, which has been changed to be a secondary module of the eighth module (of model executions) for the new SMERFS5 program.

Chapter 13 contains the SMERFS termination message and identifies some followup processing that may be required for various computer systems. The chapter also shows the format and describes the use of the optional Plot file.

Appendixes A and B show actual software reliability analyses performed on a PC for execution time and interval data types, respectively. (These are annotated copies of the optional History file.) Appendixes C and D contain listings of the optional Plot files created during the software reliability analyses contained in Appendixes A and B.

1.5 MODULE DESCRIPTION ORGANIZATION

The description of each main module of SMERFS will be divided into two or three sections. The first provides an introduction to the module and its potential use. (References 1 and 2 provide additional useful information on these modules.)

The second section traces the input/output (I/O) portion of the SMERFS execution. This section contains listings of the prompts along with necessary input and generated output. The input to SMERFS (unless otherwise specified) can include a decimal portion (i.e., most are declared to be real variables in SMERFS). The output listings of SMERFS are not limited to computational results only, but also include the various SMERFS menus, the error messages (both informative and fatal error types), and the additional listings if the user specifies a desire for the expanded assumptions and data requirements.

The material in these sections is presented in an outline-style format containing blocked text. This format was selected to allow users to expediently locate particular portions of the SMERFS execution output from the guide.

The third section contains descriptions of the various I/O values. It is not applicable to all chapters and will only be included in those containing the descriptions of the general statistics, software reliability models, and analyses of model fit modules.

1.6 FIGURE DESCRIPTIONS

To facilitate the use of this report, several figures have been inserted within the execution flow section. These figures will be placed directly after the text explaining the content of the figure. The

figures represent the cathode ray tube screen images that the user will see, but they are not the result of a SMERFS execution. The output lines have been modified to contain only the fixed portion of the lines generated by SMERFS. The variable portions, containing (during execution) computed values and Hollerith identification labels, have been replaced with the lowercase letters a, e, f, and i, for alphabetic, exponential, floating point, and integer fields, respectively. These place holders are then explained in that part of the text associated with that figure.

The type of print in the figures conveys additional information to the user (Figure 1-1). The first print style in the figure indicates that SMERFS has issued a prompt and that a response must be entered. The second print style is not a line generated by SMERFS, but is rather an inserted line indicating that one of two or more lines will appear. This strategy was adapted to lend more cohesiveness to the document by reducing the number of figures in the text. The third print style is used in all other program output. These include the computed values, error messages, and extended descriptions.

```
STYLE 1   ---   BOLD      ---   Program Prompt

STYLE 2   ---   SCRIPT    ---   Inserted Conditional Message

STYLE 3   ---   REGULAR   ---   Program Output
```

FIGURE 1-1. PRINT STYLES

1.7 PROGRAM INPUTS, OUTPUTS, AND ERROR DETECTION FACILITIES

The SMERFS program does not provide the user with a totally fool-proof environment to perform software reliability analysis; however, it will provide the user with an excellent environment if the following items are understood prior to activation.

a. Prompted values (unless otherwise specified) are read in free-format. This means that spacing does not matter and spaces or commas should be used to separate values when more than one value is prompted.

b. The program does not perform rounding of the computed estimates and predictions; however, certain tests are conducted as if rounding were performed. For example, if the model estimate for the total number of faults is 305.44 for a data set containing 305 faults, then future predictions are not allowed since the rounded value indicates all faults have been detected. Conversely, if the model estimate for the remaining number of faults is 0.61, then future predictions are allowed since the rounded value indicates a fault remains. This explains the apparent infeasibility of the prompt:

"ENTER VALUE OF M (BETWEEN ONE AND .61134E+00), OR ZERO TO END."

as one is the only valid number for M.

c. Prompted values are not "parsed" to ensure that the value is a legal character for the specific variable. For example, entry of a letter for an integer value will result in a FORTRAN error and the program will terminate.

d. Prompted values are (usually) not qualified to be appropriate when the range is specified in the prompt. For example, entry of two for the starting estimate of the probability of detecting errors (zero < input value < one) will not be detected and the program may terminate.

e. The entered values for the lengths of testing intervals should be entered as values larger than zero, and the number of faults detected in those testing periods should be entered as whole numbers (i.e., testing lengths of zero and fault counts with fractional portions will result in FORTRAN errors and the program will terminate).

CHAPTER 2

SMERFS ACCESS AND ACTIVATION

2.1 INTRODUCTION

SMERFS is designed to provide a simple, but extensive, software reliability analysis. The program has been written for interactive executions and includes both prompts and complete error detection facilities with error message generation. Perhaps the single most important decision that the user will have to make is the type of data collection to be implemented. SMERFS is designed to operate on three types of error data: Wall Clock (WC) TBF, Central Processing Unit (CPU) TBF, and interval fault count and testing length data. The user's decision on which error type is to be performed may be aided by consulting Reference 2, and Chapters 3, 10, and 11 of this report.

2.2 EXECUTION FLOW

This section explains the commands, prompts, and inputs used to initiate the SMERFS execution. (Refer to Chapter 13 for the followup instructions needed for proper data file maintenance.) The placement of and the print in the figures conform to the strategy introduced in Sections 1.5 and 1.6.

a. Commands from the Operating System Level

As with all programs, the SMERFS program is executed from the operating system level of the target computer. Although the commands vary across computers, one basic requirement is that the program executable file and any input data files have to be on a media accessible to the user. For the CDC, this implies that all are local to the interactive session. For the VAX, this implies that all are within the user's directory or within a "permitted" directory; for the PC, this implies that all are resident on the computer (preferably on the hard disk). Figure 2-1 shows the activation command for the VAX and PC.

```
For the NSWCDD 11/785 VAXCLUSTER, the program is executed by:

$RUN UDISK7:[OSMITH.SMERFS.REV5.SHIPMENT]SMERFS5

For the IBM-compatible PCs, assuming the program has been
loaded on the hard disk (C), the program is executed by:

C:SMERFS5
```

FIGURE 2-1. PROGRAM ACTIVATIONS

b.   Program Banner

Once activated, the program responds with the SMERFS banner line, including the software revision number and the release date (Figure 2-2).

```
SSSSSSS   M      M   EEEEEE   RRRRRRR   FFFFFFF   SSSSSSS
S         M M M M    E        R     R   F         S
SSSSSSS   M  M  M    EEEE     RRRRRRR   FFFF      SSSSSSS
      S   M     M    E        R   R     F               S
SSSSSSS   M     M    EEEEEE   R    R    F         SSSSSSS

    SOFTWARE REVISION NUMBER FIVE (21 SEPTEMBER 1993)
```

FIGURE 2-2. PROGRAM BANNER

c.   History File Prompt

The program prompts for the file name of the History file, the number zero if the file is not wanted, or the number one for details on the file (Figure 2-3). As shown, this file contains the program prompts, user responses, and program outputs. (Refer to Appendixes A and B for examples of this file and to Chapter 13 for followup commands.)

ERROR: If the input file name is in error (as determined by the target computer's operating system), the error message shown at the bottom of the figure is issued and the prompt is reissued.

```
ENTER OUTPUT FILE NAME FOR THE HISTORY FILE; ZERO IF THE FILE IS
NOT DESIRED, OR ONE FOR DETAILS ON THE FILE.

THE HISTORY FILE IS A COPY OF THE ENTIRE INTERACTIVE SESSION.  IT
CAN BE USED FOR LATER ANALYSIS AND/OR DOCUMENTATION.

**FILE NAME ERROR; TRY AGAIN (AFTER THE PROMPT).
```

FIGURE 2-3. HISTORY FILE PROMPT

d.   Plot File Prompt

The program prompts for the file name of the Plot file, the number zero if the file is not wanted, or the number one for details on the file (Figure 2-4). As shown, this file contains data values to be processed in a subsequent execution to produce high-quality graphs using various plotting libraries and graphic devices available to the user. (Refer to Chapter 12, step g for instructions for placing data on this file, and Chapter 13 for possible followup commands, file format, and processing instructions.)

NOTE: It is emphasized that this file merely contains sequential data values (as shown in Appendixes C and D). It does not contain actual graphic images.

ERROR: If the input file name is in error (as determined by the target computer's operating system), the error message shown at the bottom of the figure is issued and the prompt is reissued.

```
ENTER OUTPUT FILE NAME FOR THE  PLOT   FILE; ZERO IF THE FILE IS
NOT DESIRED, OR ONE FOR DETAILS ON THE FILE.

THE PLOT FILE CONTAINS SELECTED DATA AND LABELS TO ALLOW A USER-
SUPPLIED GRAPHICS PROGRAM TO GENERATE HIGH-QUALITY PLOTS.  SINCE
A CHARACTER PLOTTER IS IMPLEMENTED WITHIN THE SMERFS PROGRAM (TO
ENSURE MACHINE PORTABILITY OF THE PACKAGE),  THE USE OF THIS OP-
TION IS HIGHLY RECOMMENDED.

**FILE NAME ERROR; TRY AGAIN (AFTER THE PROMPT).
```

FIGURE 2-4. PLOT FILE PROMPT

e.   Data Type Selection

The program then prompts the user to enter the type of data to be processed (Figure 2-5). If an invalid number is entered, the same list and second prompt are output. (Refer to Chapter 3 for comments on the different data types, and Chapters 10 and 11 for information on the models available for the different data types.)

```
ENTER DESIRED DATA TYPE, OR ZERO FOR A LIST.
THE AVAILABLE DATA TYPES ARE:
 1 WALL CLOCK (WC) TIME-BETWEEN-FAILURES (TBF)
 2 CENTRAL PROCESSING UNITS (CPU) TBF
 3 WC TBF AND CPU TBF
 4 INTERVAL FAULT COUNTS AND TESTING LENGTHS
ENTER DESIRED DATA TYPE.
```

FIGURE 2-5. DATA TYPE PROMPTS

f.   Standard SMERFS File Input

The program then prompts for a flag indicating if the input of a standard SMERFS data file is desired (Figure 2-6). If a data file from a previous SMERFS execution is not available, enter zero. Otherwise, if a data file is to be input, then an affirmative response should be made and the program issues the second prompt for the WC TBF, CPU TBF, or INTERVAL file name. The program then responds with the number of elements read and the units of the TBF measurement. If the data type was entered as a three, processing for

both TBF data files occurs. The program then automatically transfers control to the Input module (Chapter 3) independent of the availability of a standard data file.

NOTE: It was not until the fifth revision of the SMERFS program that this standard SMERFS input file was altered to contain the measurement unit for the TBF data; entry of a file created by a previous revision results in the additional prompt for the units of measurement.

ENTER ONE FOR A STANDARD SMERFS FILE INPUT; ELSE ZERO.

If an affirmative response was entered, then:

ENTER INPUT FILE NAME FOR aaaaaaaa DATA.

**FILE NAME ERROR; TRY AGAIN (AFTER THE PROMPT).

If entering a TBF file created by a previous SMERFS revision, then:

THE AVAILABLE UNITS FOR TBF DATA PROCESSING ARE:
1 SECONDS   3 HOURS   5 WEEKS   7 YEARS
2 MINUTES   4 DAYS   6 MONTHS
ENTER CODE NUMBER FOR THE aaaaaaaa DATA.

THE INPUT OF iii aaaaaaaa ELEMENTS WAS PERFORMED.

Else, if entering a TBF file created by the SMERFS5 revision, then:

THE INPUT OF iii aaaaaaaa ELEMENTS WAS PERFORMED.
THESE TBF DATA WERE STORED IN aaaaaaa

Else, if entering an interval file, then:

THE INPUT OF iii aaaaaaaa ELEMENTS WAS PERFORMED.

End if

End if

FIGURE 2-6. STANDARD SMERFS FILE INPUT PROMPTS

g.   Data File Creations

The program then prompts for a flag indicating if the creation of the data file(s) is desired (Figure 2-7). Note, this prompt only occurs once in the program execution; a negative response means that the data file(s) cannot be generated at a later point within the execution. If the intent is to eventually save the data, the file must be created now (even if an error was made). If the file creation is desired, the program issues the second prompt for the WC TBF, CPU TBF, or INTERVAL file name to be assigned. The program then responds with the number of elements stored and the units of the TBF measurement. If the data type was entered as a three, processing for both TBF data files occurs. Upon completion, the

program indicates the number of elements written to the file with the message shown in the next-to-last lines of the figure. (Refer to Chapter 13 for followup commands.)

ERROR: If the input file name is in error (as determined by the target computer's operating system), the error message shown at the bottom of the figure is issued and the prompt is reissued.

```
ENTER ONE FOR THE PROGRAM TO MAKE NEW DATA FILES; ELSE ZERO. THE
RESPONSE WILL BE USED THROUGHOUT THE EXECUTION. A ZERO WILL ALSO
VOID THE DATA RESTORE OPTION IN DATA TRANSFORMATIONS.

ENTER OUTPUT FILE NAME FOR aaaaaaaa DATA.

THE FILE STORAGE OF iii aaaaaaaa ELEMENTS WAS PERFORMED.
  THESE TBF DATA ARE STORED IN aaaaaa

**FILE NAME ERROR; TRY AGAIN (AFTER THE PROMPT).
```

FIGURE 2-7. FILE CREATION OPTION AND OUTPUT MESSAGES

h.   Main Module Menu

The program prompts the user to enter the Main module option number (Figure 2-8). If an invalid option number is entered, the same list and the second prompt are output.

```
ENTER MAIN MODULE OPTION, OR ZERO FOR A LIST.
THE AVAILABLE MAIN MODULE OPTIONS ARE:
 1 DATA INPUT            6 PLOT(S) OF THE RAW DATA
 2 DATA EDIT             7 MODEL APPLICABILITY ANALYSES
 3 UNIT CONVERSIONS      8 EXECUTIONS OF THE MODELS
 4 DATA TRANSFORMATIONS  9 STOP EXECUTION OF SMERFS
 5 DATA STATISTICS
ENTER MAIN MODULE OPTION.
```

FIGURE 2-8. MAIN MODULE MENU

i.   Transfer to the Indicated Module

The program then transfers control to the indicated module, where:

1.   The Input module is contained in Chapter 3.
2.   The Edit module is contained in Chapter 4.
3.   The Unit Conversions module is contained in Chapter 5.
4.   The Transformations module is contained in Chapter 6.
5.   The General Statistics module is contained in Chapter 7.

6. The Raw Data Plot module is contained in Chapter 8.
7. The Model Applicability module is contained in Chapter 9.
8. The Model Execution module for execution time data is contained in Chapter 10 and the module for interval data is contained in Chapter 11.
9. The Stop Execution module is contained in Chapter 13.

CHAPTER 3

INPUT MODULE

3.1 INTRODUCTION

The Input module provides for the input of data via both a previously created ASCII file or the computer keyboard. Under either method of input, the data are appended to those currently existing in the program. [i.e., if a "standard" SMERFS data file was entered at the program activation (Chapter 2, step f), the values entered at this point in the execution will be appended to those. If two ASCII files are entered, then SMERFS operates on the composition of the two (after the second input).] SMERFS does not contain a re-start capability to change the data type or bring in a completely new data set. The program must be ended before a different data set can be analyzed.

Users may find this module useful in performing a segmented analysis over large error data sets. [For example, if the error collection contains 100 intervals of testing, 75 may be entered (from an ASCII file) and a complete reliability analysis performed. The remaining 25 intervals may then be entered (from another file or by the keyboard) and the reliability analysis re-conducted.] In this manner, the "growth" of the software reliability may be established. The module will also be useful for maintaining the file of error data over the testing. Here, the standard SMERFS file should be entered in Chapter 2, step f, and the current updates would be made through the input of an ASCII file or the keyboard portion of the program.

3.2 EXECUTION FLOW

This section explains the prompts and inputs for the input portion of SMERFS. The placement of and the print in the figures conform to the strategy introduced in Sections 1.5 and 1.6.

    a.   Input Option Selection

The program prompts the user to enter the type of data input to be performed (Figure 3-1). If an invalid option number is entered, the same list and second prompt are output. Briefly, the ASCII file input option implies that the user has entered the error history of either the execution times expended between consecutive failures or the interval data of fault counts and testing lengths via a program other than the SMERFS program (e.g., a clipboard editor), and desires to input that file for analysis by SMERFS. SMERFS accepts these data through "free-format" reads, so the number of records on the lines and the number of lines in the file do not affect the input. Interval data has the extra restriction that the values must be entered in pairs (where the first value reflects the fault count and the second the interval length).

```
ENTER INPUT OPTION, OR ZERO FOR A LIST.
THE AVAILABLE INPUT OPTIONS ARE:
 1 ASCII FILE INPUT
 2 KEYBOARD INPUT
 3 LIST THE CURRENT DATA
 4 RETURN TO THE MAIN PROGRAM
ENTER INPUT OPTION.
```

FIGURE 3-1. INPUT MENU

b. Transfer to the Indicated Option

If the entered input option number is four, control returns to either the Data File Creations prompt for the first access or the Main Module Menu for subsequent accesses (Chapter 2, steps g and h, respectively). Otherwise (if a valid input option number is entered), the program transfers control to the indicated input option, where:

1. The ASCII Input option is contained in Paragraph 3.2.1.
2. The Keyboard Input option is contained in Paragraph 3.2.2.
3. The Data Listing option is contained in Paragraph 3.2.3.

3.2.1 ASCII File Input

If the entered input option number is one, then:

a. If TBF data are resident in the program, SMERFS indicates the characteristics of the currently stored WC TBF and/or CPU TBF data set(s), including the number of entries and the measurement units as listed under step c. SMERFS then allows the user to abort the input if the current file does not agree with the stored data (Figure 3-2). If the response indicates a desire to abort the input, control returns to Section 3.2, step a.

```
If TBF data are resident in the program, then:

   THE FOLLOWING DATA ARE CURRENTLY RESIDENT.

   DATA TYPE    NUMBER   UNITS
   =========    ======   ======
   aaa TBF      iii      aaaaaaa

   ENTER ONE IF THE DATA TO BE ENTERED  ARE CONSISTENT IN TYPE AND
   UNITS WITH THESE; ELSE ZERO TO ABORT THIS PROCESSING.

End if
```

FIGURE 3-2. ASCII TIME UNIT CONSISTENCY PROMPT

b. The program prompts for the WC TBF, CPU TBF, or INTERVAL file name of the ASCII file (Figure 3-3). If the data type was entered as a three, processing for both TBF data files occurs. Users are reminded that the use of the ASCII file option for execution time data implies that the file contains TBF data; the module is not designed to merge testing times until a failure occurs, as is performed during the keyboard input (Paragraph 3.2.2). For interval data files, the data must be entered in pairs (where the first value reflects the fault count and the second the interval length).

ERROR: If the input file name is in error (as determined by the target computer's operating system), the error message shown at the bottom of the figure is issued and the prompt is reissued.

```
ENTER INPUT FILE NAME FOR aaaaaaa DATA.

**FILE NAME ERROR; TRY AGAIN (AFTER THE PROMPT).
```

FIGURE 3-3. ASCII FILE NAME PROMPT

c. If this is the first entry of the TBF data, SMERFS prompts for the code number of the unit measurement (Figure 3-4). If the data type was entered as a three, processing for both TBF data files occurs.

```
If TBF data were specified and data are not resident in the program, then:

   THE AVAILABLE UNITS FOR TBF DATA PROCESSING ARE:
   1 SECONDS   3 HOURS     5 WEEKS     7 YEARS
   2 MINUTES   4 DAYS      6 MONTHS
   ENTER CODE NUMBER FOR THE aaaaaaaa DATA.

End if
```

FIGURE 3-4. ASCII TIME UNIT SPECIFICATION PROMPT

d. The program then responds with a message indicating the number of values read from the specified file (Figure 3-5). If the data type was entered as a three, processing for both TBF data files occurs.

ERROR: If the number of entries exceeds 1000, the message shown at the bottom of the figure is issued and control returns to Section 3.2, step a, leaving the data vector(s) unchanged.

```
THE INPUT OF iii aaaaaaaa ELEMENTS WAS PERFORMED.

**THE NUMBER OF ENTRIES EXCEEDS THE MAXIMUM ARRAY SIZE FOR SMERFS.
```

FIGURE 3-5. FILE SIZE MESSAGES

e.   If the TBF fatality flag indicates that the final time entry of the stored data did not correspond with a failure occurrence, the first entry on the file input is added to the last stored entry, and the message shown in Figure 3-6 is issued.

```
If failure-free test time exists for the last stored entry, then:

    THE FIRST VALUE FROM THE FILE WILL BE ADDED TO THE LAST ELEMENT
    OF THE STORED DATA, SINCE THE FATALITY FLAG INDICATES A FAILURE
    HAD NOT HAPPENED ON THE FINAL ENTRY.

End if
```

FIGURE 3-6. EXECUTION TIME ADDITION MESSAGE

f.   The program then issues a message indicating the total number of values resident in the storage file(s) after the new values are added (Figure 3-7). If the data type was entered as a three, processing for both TBF data files occurs. Additionally, if TBF data are present, the program issues a prompt to determine if the new final time entry corresponds with a software failure occurrence. Upon completion, control returns to Section 3.2, step a.

ERROR: If the total number of entries exceeds 1000, the message shown in the middle of the figure is issued and control returns to Section 3.2, step a, leaving the data vector(s) unchanged.

```
    THE aaaaaaaa STORAGE SPACE NOW CONTAINS iii ELEMENTS.

**THE ADDITION WILL EXCEED THE MAXIMUM ARRAY SIZE FOR SMERFS.

If TBF data are resident in the program, then:

    ENTER ONE IF A FAILURE HAPPENED  AT THE END OF THE FINAL ENTRY,
    OR ZERO IF A FAILURE HAD NOT HAPPENED.

End if
```

FIGURE 3-7. TOTAL STORAGE MESSAGE AND FATALITY FLAG PROMPT

3.2.2 Keyboard Input

If the entered input option number is two, then:

a. If TBF data are resident in the program, SMERFS indicates the characteristics of the currently stored WC TBF and/or CPU TBF data set, including the number of entries and the measurement units as listed under step b. SMERFS then allows the user to abort the input if the current file does not agree with the stored data (Figure 3-8). If the response indicates a desire to abort the input, control returns to Section 3.2, step a.

> NOTE: If WC TBF data are being input, SMERFS issues the extra message that the measurement units only pertain to the data storage. The program still assumes that the WC values will be entered in 24 hour units. This is explained further in step c.

```
If TBF data are resident in the program, then:

  THE FOLLOWING DATA ARE CURRENTLY RESIDENT.

    DATA TYPE    NUMBER    UNITS
    =========    ======    =======
    aaa TBF      iii       aaaaaaa

  ENTER ONE IF THE DATA TO BE ENTERED  ARE CONSISTENT IN TYPE AND
  UNITS WITH THESE; ELSE ZERO TO ABORT THIS PROCESSING.

  If WC TBF data are present, then:

  NOTE WC TBF DATA ARE ENTERED IN 24 HOUR UNITS AND STORED IN THE
  UNITS OF THE CURRENT DATA, aaaaaaa.

  End if

End if
```

FIGURE 3-8. KEYBOARD TIME UNIT CONSISTENCY PROMPT

b. If this is the first entry of the TBF data, SMERFS prompts for the code number of the unit measurement (Figure 3-9). If the data type was entered as a three, processing for both TBF data files occurs.

> NOTE: If WC TBF data are being input, SMERFS issues the extra message that the measurement units only pertain to the data storage. The program still assumes that the WC values will be entered in 24 hour units. This is explained further in step c.

```
If TBF data were specified and data are not resident in the program, then:

   THE AVAILABLE UNITS FOR TBF DATA PROCESSING ARE:
   1 SECONDS    3 HOURS      5 WEEKS      7 YEARS
   2 MINUTES    4 DAYS       6 MONTHS
   ENTER CODE NUMBER FOR THE aaaaaaa DATA.

If WC TBF data were specified, then:

   NOTE WC TBF DATA ARE ENTERED IN 24 HOUR UNITS AND STORED IN THE
   SPECIFIED UNITS, aaaaaaa.

End if

End if
```

FIGURE 3-9. KEYBOARD TIME UNIT SPECIFICATION PROMPT

c. If WC TBF data are being input (data type was entered as a one), SMERFS issues a message telling the user how to terminate the input sequence (Figure 3-10). It then repeatedly prompts for the starting and ending times of testing (24-hour units), the number of failures observed within that session, and, if any software failures were observed, the time(s) of the failure(s) (again, in 24-hour units). SMERFS then converts these actual times into the TBF execution units as directed in step a or b. Upon completion (as indicated through either user direction or error), control returns to Section 3.2, step a.

ERROR: The current SMERFS software can handle up to 1000 entries, which may equate to thousands of testing sessions; the program continually merges the testing times until a failure is observed. When the number of entries exceeds 1000, the message shown at the bottom of the figure is issued and control returns to Section 3.2, step a.

```
A RESPONSE OF NEGATIVE VALUES FOR THE PROMPT:
 "ENTER STARTING & ENDING TIMES; AND NUMBER OF FAILURES."
WILL END THE PROCESSING.

ENTER STARTING & ENDING TIMES; AND NUMBER OF FAILURES.
 ENTER TIME OF FAILURE NUMBER iii.

**THE NUMBER OF ENTRIES EXCEEDS THE MAXIMUM ARRAY SIZE FOR SMERFS.
```

FIGURE 3-10. WC DATA INPUT PROMPTS

d. If CPU TBF data are being input (data type was entered as a two), SMERFS issues a message telling the user how to terminate the input sequence (Figure 3-11). It then repeatedly prompts for the expended CPU time and a flag of zero or one. No unit

conversions are performed on the input values; hence, the values input must agree with those identified in step a or b. A flag of one indicates that the testing session was terminated with a failure occurrence; a zero indicates that a failure was not observed. If a value other than zero or one was entered, the program issues the message in the next-to-last line of the figure and the flag is re-entered. Upon completion (as indicated through either user direction or error), control returns to Section 3.2, step a.

ERROR: The current SMERFS software can handle up to 1000 entries, which may equate to thousands of testing sessions; the program continually merges the testing times until a failure is observed. When the number of entries exceeds 1000, the message shown at the bottom of the figure is issued and control returns to Section 3.2, step a.

```
A RESPONSE OF NEGATIVE VALUES FOR THE PROMPT:
 "ENTER CPU; AND ONE IF A FAILURE HAPPENED, OR ZERO IF NOT."
WILL END THE PROCESSING.

ENTER CPU; AND ONE IF A FAILURE HAPPENED, OR ZERO IF NOT.

**THE SECOND VALUE MUST BE ZERO OR ONE; RE-ENTER THAT VALUE.
**THE NUMBER OF ENTRIES EXCEEDS THE MAXIMUM ARRAY SIZE FOR SMERFS.
```

FIGURE 3-11. CPU DATA INPUT PROMPT

e. If both WC TBF and CPU TBF data are being input (data type was entered as a three), the program issues a message telling the user how to terminate the input sequence (Figure 3-12). As in the case of the WC keyboard input, SMERFS repeatedly prompts for the starting and ending times of testing (in 24-hour units) and the number of failures observed in that testing session. If any software failures occurred in that session, SMERFS prompts for both the failure time (again in 24-hour units) and the associated CPU time expenditure for each failure. SMERFS then stores the WC execution time in the units as directed in step a or b. (No conversions are again performed during the storage of the CPU execution times.) If the final failure was observed before the end of the testing session, SMERFS prompts for the expended CPU time between the last failure and the end of the testing session. If no software failures were detected in the session, SMERFS prompts for the entire CPU time expenditure for the session. Upon completion (as indicated through either user direction or error), control returns to Section 3.2, step a.

ERROR: The current SMERFS software can handle up to 1000 entries, which may equate to thousands of testing sessions; the program continually merges the testing times until a failure is observed. When the number of entries exceeds 1000, the message shown at the bottom of the figure is issued and control returns to Section 3.2, step a.

```
A RESPONSE OF NEGATIVE VALUES FOR THE PROMPT:
 "ENTER STARTING & ENDING TIMES; AND NUMBER OF FAILURES."
WILL END THE PROCESSING.

ENTER STARTING & ENDING TIMES; AND NUMBER OF FAILURES.
 ENTER TIME OF FAILURE NUMBER iii.
 ENTER ASSOCIATED CPU EXPENDED.
 ENTER LAST FAILURE-FREE CPU.

**THE NUMBER OF ENTRIES EXCEEDS THE MAXIMUM ARRAY SIZE FOR SMERFS.
```

FIGURE 3-12. WC AND CPU DATA INPUT PROMPTS

d.   If interval data are being input (data type was entered as a four), the program issues a message telling the user how to terminate the input sequence (Figure 2-13). It then repeatedly prompts for the number of faults detected in the testing interval and the associated testing length of that interval. No conversion or merging of the input values is performed. Upon completion (as indicated through either user direction or error), control returns to Section 3.2, step a.

ERROR: The current SMERFS software can handle up to 1000 pairs of values. When the number of pairs exceeds 1000, the message shown at the bottom of the figure is issued and control returns to Section 3.2, step a.

```
A RESPONSE OF NEGATIVE VALUES FOR THE PROMPT:
 "ENTER FAULT COUNT AND TESTING LENGTH."
WILL END THE PROCESSING.

ENTER FAULT COUNT AND TESTING LENGTH.

**THE NUMBER OF ENTRIES EXCEEDS THE MAXIMUM ARRAY SIZE FOR SMERFS.
```

FIGURE 3-13. INTERVAL DATA INPUT PROMPT

3.2.3 List the Current Data

If the entered input option number is three, SMERFS generates one of three possible reports (Figure 3-14). The first report type is for WC TBF or CPU TBF data (data type was entered as a one or two). The columns of this report contain consecutive numbers for identification purposes and the TBF data values, measured in either WC or CPU units. The alphabetic field in the second column will be set to the measurement units, and the alphabetic field appearing in the third column is set to "FAILURE-FREE" if the last entered time was not associated with a software failure occurrence. The second report type is for WC TBF and CPU TBF data (data type was entered as a three). This report contains the same information as the first, but contains information for both sets of data. The third report type is for

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interval data (data type was entered as a four) and includes columns containing the interval number, the number of software faults occurring in that interval, and the associated testing length of the interval. Upon completion, control returns to Section 3.2, step a.

```
If WC TBF or CPU TBF data are present, then:

    FAILURE      TIME-BETWEEN
    NUMBER       aaaaaaa
    ========     ===============
      iii        ●●●●●●●●●●●●
       •            •
       •            •
      iii        ●●●●●●●●●●●●       aaaaaaaaaaaaaa

Else, if WC TBF and CPU TBF data are present, then:

    FAILURE      WALL CLOCK TBF       CPU TBF
    NUMBER       aaaaaaa              aaaaaaa
    ========     ===============      ===============
      iii        ●●●●●●●●●●●●          ●●●●●●●●●●●●
       •            •                    •
       •            •                    •
      iii        ●●●●●●●●●●●●          ●●●●●●●●●●●●
      iii        ●●●●●●●●●●●●          ●●●●●●●●●●●●       aaaaaaaaaaaaaa

Else, if interval data are present, then:

    INTERVAL     NO. OF FAULTS        TESTING LENGTH
    ========     ===============      ===============
      iii        ●●●●●●●●●●●●          ●●●●●●●●●●●●
       •            •                    •
       •            •                    •
      iii        ●●●●●●●●●●●●          ●●●●●●●●●●●●

End if
```

FIGURE 3-14. DATA LIST OUTPUT

CHAPTER 4

EDIT MODULE

4.1 INTRODUCTION

The Edit module permits altering of the software error data vector(s). All data updates should be performed using the same units of measurement as in the data vector(s). Through the allowed options, the user can obtain a listing of the data and perform various types of data modification. These modifications may be the result of an incorrectly entered data value, a software error being investigated and subsequently determined not to be a true software error, or the omission of a data value during input. Once modified, the new data vector may be placed in the data file (if a file was generated as specified in Chapter 2, step g), or the data values can be retained locally without affecting the values in the data file. This last option allows the user to explore various apparent patterns appearing in the software error data, without necessarily destroying the current data file.

4.2 EXECUTION FLOW

This section explains the prompts and inputs for the edit portion of SMERFS. The placement of and the print in the figures conform to the strategy introduced in Sections 1.5 and 1.6.

a. Edit Option Selection

The program prompts the user to enter the type of edit to be performed (Figure 4-1). If an invalid option number is entered, the same list and second prompt are output.

```
ENTER EDIT OPTION, OR ZERO FOR A LIST.
THE AVAILABLE EDIT OPTIONS ARE:
 1 CHANGE SPECIFIED ELEMENT
 2 DELETE SPECIFIED ELEMENT(S)
 3 INSERT UP TO 10 ELEMENTS
 4 COMBINE TWO OR MORE ADJACENT ELEMENTS
 5 CHANGE THE TBF FATALITY FLAG
 6 LIST THE CURRENT DATA
 7 RETURN TO THE MAIN PROGRAM
ENTER EDIT OPTION.
```

FIGURE 4-1. EDIT MENU

b. Change Specified Element

If the entered edit option number is one, SMERFS prompts for the location number to be changed and the new value to be placed in that location of the data vector (Figure 4-2). If the data type was entered as a three or four, SMERFS also prompts for a second value to be placed in the second data vector. (The second vector contains the CPU TBF entries for data type three, and the interval testing lengths for data type four.) Upon completion, control returns to step a.

WARNING: If the last entry of a TBF data vector is changed, the reminder message shown at the bottom of the figure is issued prior to the return.

ERROR: If the location number of the change(s) is in error, the message shown in the next-to-last line of the figure is issued and control returns to step a, leaving the data vector(s) unchanged.

```
   ENTER LOCATION NUMBER AND NEW VALUE FOR DATA 1.

If WC TBF and CPU TBF data, or interval data, then:

   ENTER NEW VALUE FOR DATA 2.

End if

 **THE EDIT EXCEEDS BOUNDS OF THE CURRENT DATA.

  ENSURE THE TBF FATALITY FLAG IS PROPERLY SET.
```

FIGURE 4-2. CHANGE A SPECIFIED ELEMENT

c. Delete Specified Element(s)

If the entered edit option number is two, SMERFS prompts for the inclusive starting and ending location numbers to be deleted from the data vector(s) (Figure 4-3). To delete a single element, the same number should be repeated. Upon completion, control returns to step a.

WARNING: If the end of a TBF data vector is deleted, the reminder message shown at the bottom of the figure is issued prior to the return.

ERROR: If either location number of the deletion is in error, the message shown in the next-to-last line of the figure is issued and control returns to step a, leaving the data vector(s) unchanged.

```
ENTER STARTING AND ENDING LOCATIONS TO DELETE.

**THE EDIT EXCEEDS BOUNDS OF THE CURRENT DATA.

ENSURE THE TBF FATALITY FLAG IS PROPERLY SET.
```

FIGURE 4-3. DELETE SPECIFIED ELEMENT(S)

d.   Insert up to 10 Elements

If the entered edit option number is three, SMERFS prompts for the location number just prior to the insert and the number of new values (maximum 10) to be placed in the data vector(s) (Figure 4-4). The location number can be entered as zero to cause insertions at the beginning of the data. SMERFS then prompts for the new values to be placed in the data vector, and will additionally prompt for a second set of values to be placed in the second data vector if the data type was entered as a three or four. (The second vector contains the CPU TBF entries for data type three, and the interval testing lengths for data type four.) Upon completion, control returns to step a.

WARNING: If the insertion is performed at the end of a TBF data vector, the reminder message shown at the bottom of the figure is issued prior to the return.

ERROR: If the location number of the insertion is in error or the indicated insertion causes the number of entries to exceed 1000, the appropriate message shown in the next-to-last lines of the figure is issued and control returns to step a, leaving the data vector(s) unchanged.

```
   ENTER LOCATION NUMBER JUST PRIOR TO THE INSERTION AND NUMBER OF
   NEW ENTRIES.

   ENTER i ELEMENT(S) FOR DATA 1.

If WC TBF and CPU TBF data, or interval data, then:

   AND   i ELEMENT(S) FOR DATA 2.

End if

**THE EDIT EXCEEDS BOUNDS OF THE CURRENT DATA.
**THE INSERTION WILL EXCEED THE MAXIMUM ARRAY SIZE FOR SMERFS.

   ENSURE THE TBF FATALITY FLAG IS PROPERLY SET.
```

FIGURE 4-4. INSERT UP TO 10 ELEMENTS

e.   Combine Two or More Adjacent Elements

If the entered edit option number is four, SMERFS prompts for the inclusive starting and ending location numbers that are to be combined in the data vector(s) (Figure 4-5). Upon completion, control returns to step a.

WARNING: If the end of a TBF data vector is involved in the data merge, the reminder message shown at the bottom of the figure is issued prior to the return.

ERROR: If either location number of the data merge is in error, the message shown in the next-to-last line of the figure is issued and control returns to step a, leaving the data vector(s) unchanged.

```
ENTER STARTING AND ENDING LOCATIONS TO MERGE.

**THE EDIT EXCEEDS BOUNDS OF THE CURRENT DATA.

ENSURE THE TBF FATALITY FLAG IS PROPERLY SET.
```

FIGURE 4-5. COMBINE ADJACENT ELEMENTS

f.   Change the TBF Fatality Flag

If the entered edit option number is five, SMERFS changes the value of the fatality flag for the final entry in the TBF data vector(s) (i.e., if the last entry was recorded as being terminated with the observation of a software failure, the fatality flag is changed to indicate that it was not). The appropriate processing message shown in Figure 4-6 is then issued and control returns to step a.

ERROR: If interval data are resident (data type was entered as a four), the error message shown at the bottom of the figure is issued and control returns to step a, leaving the data vector(s) unchanged.

```
THE FATALITY FLAG HAS BEEN SET TO INDICATE A FAILURE  OCCURRED
AT THE END OF THE TESTING.

THE FATALITY FLAG FOR THE LAST DATA POINT HAS BEEN SET TO INDI-
CATE THAT A FAILURE OCCURRED FOR THE PREVIOUS DATA POINT.

**THIS OPTION IS NOT APPLICABLE FOR INTERVAL DATA.
```

FIGURE 4-6. CHANGE THE TBF FATALITY FLAG

4-4

g.   List the Current Data

If the entered edit option number is six, SMERFS generates one of three possible reports. The reports are the same as those described in Paragraph 3.2.3. Upon completion, control returns to step a.

h.   Return to the Main Module

If the entered edit option number is seven, the data editing is over and the user has requested a return to the Main Module Menu (Chapter 2, step h). Before the return is performed, SMERFS determines if the output data file(s) was opened during the data input (Chapter 2, step g) and if any elements were changed. If both tests showed true, SMERFS allows the user the opportunity to update the WC TBF, CPU TBF, or INTERVAL data files to reflect those changes by issuing the prompt shown in Figure 4-7. If the update is requested, the program responds with the number of elements stored and the units of the TBF measurement. If the data type was entered as a three, processing for both TBF data files occurs. It is strongly advised that both receive the same user response. Updating one file and not the other may cause errors in subsequent attempts to analyze the two data files in a combined execution. Upon completion, control returns to the Main Module Menu (Chapter 2, step h).

```
ENTER ONE TO SAVE THE NEW aaaaaaaa DATA; ELSE ZERO.

THE FILE STORAGE OF iii aaaaaaaa ELEMENTS WAS PERFORMED.
THESE TBF DATA ARE STORED IN aaaaaaa
```

FIGURE 4-7. FILE UPDATE OPTION AND OUTPUT MESSAGE

CHAPTER 5

UNIT CONVERSIONS MODULE

5.1 INTRODUCTION

The Unit Conversions module permits a specialized data transformation of the TBF data vector(s). Since the software reliability models for execution time data generate the estimates and predictions in units analogous to those of the stored failure history, it may be appropriate to alter the storage measurements to a different time unit. This type of transformation is achieved through a series of multiplications or divisions using the following scale factors:

 a. 60.0 for seconds to minutes
 b. 60.0 for minutes to hours
 c. 24.0 for hours to days
 d. 07.0 for days to weeks
 e. 04.0 for weeks to months
 f. 12.0 for months to years

For example, if the data are recorded in minutes and weeks are desired, then each element of the storage array is divided by 60 (to get the hours), divided again by 24 (to get the days), and then divided a final time by 7 (to get the weeks). If more exact conversions are required, the Transformation Module (Chapter 6) may be used.

Once modified, the new data vector may be placed in the data file (if a file was generated as specified in Chapter 2, step g), or the data values can be retained locally without affecting the values in the data file. This last option allows the user to obtain the model estimates and predictions in the desired units, without destroying the current data file. Experience has also shown that the conversion of units may be a useful technique to achieve successful convergence for certain data sets (i.e., models that terminate with an error message may converge when the units are changed). If there are large TBF data values, considering time units which are too small (i.e., seconds or minutes) may result in problems of overflow due to the functions that are being calculated for the various models. Larger time intervals (i.e., hours or days) may eliminate this problem. Conversely, if the TBF data values are small, using small time units may aid in preventing underflow of the computations.

5.2 EXECUTION FLOW

This section explains the prompts and inputs for the edit portion of SMERFS. The placement of and the print in the figures conform to the strategy introduced in Sections 1.5 and 1.6.

a. Data Type Selection

If WC TBF and CPU TBF data are resident (data type was entered as a three), the program prompts the user to enter the type of data to be converted (Figure 5-1). If an invalid number is entered, the error message is issued and the prompt is reissued.

ERROR: If interval data are resident (data type was entered as a four), the error message shown at the bottom of the figure is issued and control returns to the Main Module Menu (Chapter 2, step h).

```
If WC TBF and CPU TBF data, then:

ENTER ONE FOR WC TBF OR TWO FOR CPU TBF.

**DATA TYPE ERROR; TRY AGAIN (AFTER THE PROMPT).

Else, if interval data, then:

**THIS OPTION IS NOT APPLICABLE FOR INTERVAL DATA.

End if
```

FIGURE 5-1. DATA TYPE PROMPT

b. Conversion Unit Prompt

The program then displays the units of the stored data, lists the available measurement units, and prompts the user to enter the number of the desired units (Figure 5-2).

```
THE aaaaaaaa DATA ARE CURRENTLY STORED IN aaaaaaa.

THE DATA MAY BE CONVERTED TO THE FOLLOWING UNITS:
  1 SECONDS    3 HOURS     5 WEEKS      7 YEARS
  2 MINUTES    4 DAYS      6 MONTHS
ENTER NEW CODE NUMBER FOR THE DATA.
```

FIGURE 5-2. DESIRED MEASUREMENT UNIT PROMPT

c. List the Current Data

SMERFS prompts the user to determine if the listing (containing the converted data) is desired (Figure 5-3). If the listing is desired, SMERFS generates one of two possible reports. The reports are the same as the first two described in Paragraph 3.2.3.

```
ENTER ONE TO LIST THE CURRENT DATA; ELSE ZERO.
```

FIGURE 5-3. DATA LIST OPTION

d.   Return to the Main Module

If the output data file(s) was opened during the data input (Chapter 2, step g), SMERFS allows the user the opportunity to update the WC TBF or CPU TBF file (Figure 5-4). If the file update is desired, the program responds with the number of elements stored and the (new) units of the TBF measurement. Upon completion, control returns to the Main Module Menu (Chapter 2, step h).

```
ENTER ONE TO SAVE THE NEW aaaaaaaa DATA; ELSE ZERO.

THE FILE STORAGE OF iii aaaaaaaa ELEMENTS WAS PERFORMED.
THESE TBF DATA ARE STORED IN aaaaaaa
```

FIGURE 5-4. FILE UPDATE OPTION AND OUTPUT MESSAGE

CHAPTER 6

TRANSFORMATION MODULE

6.1 INTRODUCTION

The Transformation module permits scaling of a software error data vector. Five types of transformations are allowed along with the options of restoring the data vector to its non-transformed state and listing the data. The Transformation module operates only on a single data vector. The two TBF vectors cannot be transformed together, nor can the interval fault counts and testing lengths. Additionally, the transformed data are held locally. If the retention of the transformed data is desired, it may be done by entering the Edit module (Chapter 3), making a dummy edit (i.e., changing a location's value to the current value), and then allowing the Edit module to perform the data file update.

6.2 EXECUTION FLOW

This section explains the prompts and inputs for the transformation portion of SMERFS. The placement of and the print in the figures conform to the strategy introduced in Sections 1.5 and 1.6.

    a.   Data Type Selection

        If WC TBF and CPU TBF data or interval data are resident (data type was entered as a three or four), SMERFS prompts the user to enter the type of data to be transformed (Figure 6-1). If an invalid number is entered, the error message shown at the bottom of the figure is issued and the appropriate prompt is reissued.

```
If WC TBF and CPU TBF data, then:

  ENTER ONE FOR WC TBF OR TWO FOR CPU TBF.

Else, if interval data, then:

  ENTER ONE FOR COUNTS OR TWO FOR LENGTHS;  THE RESTORATION OPTION
  (#6) WILL AFFECT BOTH THE COUNT AND LENGTH DATA.

End if

**DATA TYPE ERROR; TRY AGAIN (AFTER THE PROMPT).
```

FIGURE 6-1. DATA TYPE PROMPTS

b.   Transformation Option Selection

The program then prompts the user to enter the type of transformation to be performed (Figure 6-2). If an invalid option number is entered, the same list and second prompt are output.

```
ENTER TRANSFORMATION OPTION, OR ZERO FOR A LIST.
THE AVAILABLE TRANSFORMATION OPTIONS ARE:
1 LOG(A * X(I) + B)        5 X * A
2 EXP(A * X(I) + B)        6 RESTORE THE DATA
3 X ** A                   7 LIST THE CURRENT DATA
4 X + A                    8 RETURN TO THE MAIN PROGRAM
ENTER TRANSFORMATION OPTION.
```

FIGURE 6-2. TRANSFORMATION MENU

c.   Transformations Using Two Scale Factors

If the entered transformation option number is one or two, SMERFS prompts for the two transformation scale factors (Figure 6-3). Upon completion, control returns to step b.

ERROR: If, in attempting a transformation type one, the log of a non-positive number is encountered, the message shown at the bottom of the figure is issued and control returns to step b, leaving the data vector unchanged.

```
ENTER VALUES OF A AND B.

**TRANSFORMATION ILLEGAL - NEGATIVE OR ZERO A * X(I) + B.
```

FIGURE 6-3. PROMPT FOR TWO SCALE FACTORS

d.   Transformations Using One Scale Factor

If the entered transformation option number is three, four, or five, SMERFS prompts for the transformation scale factor (Figure 6-4). Upon completion, control returns to step b.

ERROR: If a negative number is encountered when attempting a transformation type three with a scale factor containing a decimal portion, the message shown at the bottom of the figure is issued and control returns to step b, leaving the data vector unchanged.

```
 ENTER VALUE OF A.

**TRANSFORMATION ILLEGAL - NEGATIVE X(I).
```

FIGURE 6-4. PROMPT FOR ONE SCALE FACTOR

e. Restore the Data

If the entered transformation option number is six, SMERFS rewinds the appropriate data file and enters the data values. (If interval data are being transformed, restoration causes the input of both the fault counts and the testing lengths.) The program responds with the number of elements read and the units of the TBF measurement (Figure 6-5). Upon completion, control returns to step b.

ERROR: If the output data file was not opened in Chapter 2, step g, the error message shown at the bottom of the figure is issued and control returns to step b, leaving the data vector unchanged.

```
 THE INPUT OF iii aaaaaaaa ELEMENTS WAS PERFORMED.
 THESE TBF DATA WERE STORED IN aaaaaaa

**RESTORATION NOT POSSIBLE; NEW DATA FILES WERE NOT CREATED.
```

FIGURE 6-5. DATA RESTORATION MESSAGES

f. List the Current Data

If the entered transformation option number is seven, SMERFS generates one of three possible reports. The reports are the same as those described in Paragraph 3.2.3. Upon completion, control returns to step b.

g. Return to the Main Module

If the entered transformation option number is eight, control returns to the Main Module Menu (Chapter 2, step h).

CHAPTER 7

GENERAL STATISTICS MODULE

7.1 INTRODUCTION

The General Statistics module provides general summary statistics of the software error data. The processing necessary to generate and output these statistics is internal and requires no additional information or direction from the user.

7.2 EXECUTION FLOW

This section explains the module flow in the generation of the statistics table(s). The placement of and the print in the figure conform to the strategy introduced in Sections 1.5 and 1.6. (Refer to Section 7.3 for descriptions of some of the values within these reports.)

a.   WC TBF or CPU TBF

If the data type was entered as a one or two, the first report type in Figure 7-1 is generated with a WC TBF or CPU TBF header. The remaining place holders are replaced with the indicated values.

b.   WC TBF and CPU TBF

If the data type was entered as a three, the first report type is generated twice (once for each type of data).

c.   Interval Fault Counts with Equal Testing Lengths

If the data type was entered as a four and the testing lengths are the same in all periods, the second report type is generated.

d.   Interval Fault Counts with Unequal Testing Lengths

If the data type was entered as a four and the testing lengths are not the same in all periods, the third report type is generated.

e.   Return to the Main Module

Control returns to the Main Module Menu (Chapter 2, step h).

```
If WC TBF and/or CPU TBF data, then:

                        aaa TIME-BETWEEN-FAILURES
                        RECORDED IN aaaaaaa
                        WITH TOTAL TESTING TIME OF  eeeeeeeeeeeee
                        AND TIME OF LAST FAILURE OF eeeeeeeeeeeee
                        *************************************************
     MEDIAN OF THE DATA   *             eeeeeeeeeeeeee              *
     LOWER & UPPER HINGES *   eeeeeeeeeeeeee    eeeeeeeeeeeeee      *
     MINIMUM AND MAXIMUM  *   eeeeeeeeeeeeee    eeeeeeeeeeeeee      *
     NUMBER OF ENTRIES    *                 iii                    *
     AVERAGE OF THE DATA  *             eeeeeeeeeeeeee              *
     STD. DEV. & VARIANCE *   eeeeeeeeeeeeee    eeeeeeeeeeeeee      *
     SKEWNESS & KURTOSIS  *   eeeeeeeeeeeeee    eeeeeeeeeeeeee      *
                        *************************************************


Else, if interval data (with equal testing lengths), then:

                        INTERVAL DATA WITH EQUAL LENGTHS
                        WITH FAULT COUNTS TOTALING TO iiiiiiiiiii
                        *************************************************
     MEDIAN OF THE DATA   *             eeeeeeeeeeeeee              *
     LOWER & UPPER HINGES *   eeeeeeeeeeeeee    eeeeeeeeeeeeee      *
     MINIMUM AND MAXIMUM  *   eeeeeeeeeeeeee    eeeeeeeeeeeeee      *
     NUMBER OF ENTRIES    *                 iii                    *
     AVERAGE OF THE DATA  *             eeeeeeeeeeeeee              *
     STD. DEV. & VARIANCE *   eeeeeeeeeeeeee    eeeeeeeeeeeeee      *
     SKEWNESS & KURTOSIS  *   eeeeeeeeeeeeee    eeeeeeeeeeeeee      *
                        *************************************************


Else, if interval data (with unequal testing lengths), then:

                        INTERVAL DATA WITH VARYING LENGTHS
                        *************************************************
                        *------------ FAULT COUNTS ------------*
     MEDIAN OF THE DATA   *             eeeeeeeeeeeeee              *
     LOWER & UPPER HINGES *   eeeeeeeeeeeeee    eeeeeeeeeeeeee      *
     MINIMUM AND MAXIMUM  *   eeeeeeeeeeeeee    eeeeeeeeeeeeee      *
                        *----------- INTERVAL LENGTHS -----------*
     MEDIAN OF THE DATA   *             eeeeeeeeeeeeee              *
     LOWER & UPPER HINGES *   eeeeeeeeeeeeee    eeeeeeeeeeeeee      *
     MINIMUM AND MAXIMUM  *   eeeeeeeeeeeeee    eeeeeeeeeeeeee      *
                        *------------ COMBINATION -------------*
     COUNT & LENGTH TOTALS*   eeeeeeeeeeeeee    eeeeeeeeeeeeee      *
     RATIO OF THE PRIOR   *             eeeeeeeeeeeeee              *
     NUMBER OF ENTRIES    *                 iii                    *
                        *************************************************

End if
```

FIGURE 7-1. GENERAL STATISTICS REPORTS

7.3 VALUES DESCRIPTIONS

The median of the data (Figure 7-1) is a measure of central tendency. It represents the value such that 50 percent of the data have values below it; analogously, 50 percent of the values are greater.

The lower and upper hinges represent a breakup of each of the two sections of the data, determined by the median, into two equal parts. Thus, the first value of the hinge has 25 percent of the data points being smaller (75 percent therefore being larger) and the second has 75 percent being smaller (25 percent therefore being larger). They both are a measure of the spread of the data (Reference 3).

The minimum and maximum values are, respectively, the smallest and largest values in the data base; the number of entries simply shows the number of points in the data base.

For the first two report types, the summary statistics also include the average, standard deviation, sample variance, skewness, and kurtosis. The skewness is a measure of the symmetry of the sample and the kurtosis indicates how "peaked" the sample is.

For the third report type, the summary statistics include the total number of faults found, the total amount of testing time, the ratio of the two totals (showing an estimate for the number of faults detected per testing period), and the number of points in the data base.

CHAPTER 8

RAW DATA PLOT MODULE

8.1 INTRODUCTION

The Raw Data Plot module generates plots of the software error data. The term "raw data" is used to show that the plot is of the actual data rather than data from a software reliability prediction. The plots are the result of an internal line printer plotter. The internal plotter produces very crude graphs to assist the user in quick interactive examination of the data. It is, however, highly recommended that users make use of the optional Plot file (Chapter 2, step d) to produce high-quality plots. Examples of this file can be found in Appendixes C and D.

8.2 EXECUTION FLOW

This section explains the prompts and input for the raw data plot portion of SMERFS. The placement of and the print in the figures conform to the strategy introduced in Sections 1.5 and 1.6.

a. Data Type Selection

If WC TBF and CPU TBF data are resident (data type was entered as a three), the program prompts the user to enter the type of data to be plotted (Figure 8-1). If an invalid number is entered, the message shown at the bottom of the figure is issued and the prompt is reissued.

```
If WC TBF and CPU TBF data, then:

    ENTER ONE FOR WC TBF OR TWO FOR CPU TBF.

  **DATA TYPE ERROR; TRY AGAIN (AFTER THE PROMPT).

End if
```

FIGURE 8-1. DATA TYPE PROMPT

b. Title Prompts

SMERFS then prompts for the plot title for either the execution TBF data or the interval fault count data (Figure 8-2). SMERFS is designed to generate a second plot of the interval

testing lengths; however, the title for that plot is not prompted until it is determined if the user desires the plot to be generated (step e). For correct centering on the plot, the title(s) should be centered in the 30-character field.

```
If interval data, then:

   ENTER A COUNT PLOT TITLE (UP TO 30 CHARACTERS).

Else, if TBF data, then:

   ENTER A PLOT TITLE (UP TO 30 CHARACTERS).

End if
```

FIGURE 8-2. TITLE PROMPTS

c.   Smoothing Prompt

If the sample size is greater than six, SMERFS prompts the user to determine if smoothing of the WC DATA, CPU DATA, or COUNT DATA is desired (Figure 8-3). The smoothing technique is described in Reference 7.

```
ENTER ONE TO SMOOTH THE aaaaaaaaaa; ELSE ZERO.
```

FIGURE 8-3. SMOOTHING PROMPT

d.   Plot Generations

The plot is then generated (Figure 8-4), including the user-specified title and the program-determined axis labels. The units for the TBF measurement will also be placed on the plot as a second y-axis label.

The plotter can only reflect a maximum of 50 elements on the x-axis. The message shown in the last line of Figure 8-4 not only provides for a pause between plots, but also allows for termination of the plotting.

NOTE: The minimum and maximum values for the y-axis are defined over all values to be plotted, not just those reflected in the plot of 50 points.

```
                    aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa

●●●●●●●●●●●●●  I
             I
             I
             I           * = original data
             I
             I
             I
aaaaaa       I
aaaaaaa      I
             I
             I
             I
             I
             I                      .
             I
             I
●●●●●●●●●●●●● I
             +----------+----------+----------+----------+----------+
           iii        iii        iii        iii        iii        iii

                              aaaaaaaaaa

ENTER ONE TO VIEW THE NEXT SECTION; ELSE ZERO TO EXIT PLOTTER.
```

FIGURE 8-4. PLOT FORMAT AND PROMPTS

e.   Length Plot Prompts

If interval data are resident (data type was entered as a four), the program prompts the user to determine if the plot of the interval testing lengths is desired (Figure 8-5). This option exists because the lengths are usually set to one; and therefore, the plot is not needed. If an affirmative response is made, then the title line is prompted and a plot similar to that shown in Figure 8-4 is generated. (The second y-axis label is set to blanks for the interval plot.)

```
ENTER ONE FOR ASSOCIATED LENGTH PLOT; ELSE ZERO.

ENTER A LENGTH PLOT TITLE (UP TO 30 CHARACTERS).
```

FIGURE 8-5. LENGTH PLOT PROMPTS

f.   Return to the Main Module

After the plotting, the routine automatically returns control to the Main Module Menu (Chapter 2, step h).

CHAPTER 9

MODEL APPLICABILITY MODULE

9.1 INTRODUCTION

The Model Applicability module performs the applicability analyses as proposed by Bev Littlewood (Reference 5). Quoting the abstract of that reference:

"Different software reliability models can produce very different answers when called upon to predict future reliability in a reliability growth context. Users need to know which, if any, of the competing predictions are trustworthy. Some techniques are presented which form the basis of a partial solution to this problem. In addition, it is shown that this approach can point the way towards more accurate predictions via models which learn from past behaviour."

All four analyses [Accuracy (Prequential Likelihood), Bias, Noise, and Trend] have been implemented for the execution time models. Only the Accuracy has been implemented for the interval data models.

9.2 EXECUTION FLOW

This section explains the prompts and inputs for the model applicability portion of SMERFS. The placement of and the print in the figures conform to the strategy introduced in Sections 1.5 and 1.6.

a. Data Type Selection

If WC TBF and CPU TBF data are resident (data type was entered as a three), the program prompts the user to enter the type of data to be analyzed (Figure 9-1). If an invalid number is entered, the error message shown at the bottom of the figure is issued and the prompt is reissued.

```
If WC TBF and CPU TBF data, then:

  ENTER ONE FOR WC TBF OR TWO FOR CPU TBF.

**DATA TYPE ERROR; TRY AGAIN (AFTER THE PROMPT).

End if
```

FIGURE 9-1. DATA TYPE PROMPT

b.   Analysis Range Specification

SMERFS then indicates the range over which each analysis will take place (Figure 9-2). The limits are set to one-half and one less than the number of failures for execution time data. Similarly, the limits are set to one-half and one less than the number of periods for interval data. If the values are acceptable, enter a zero. Otherwise, if new limits are desired, then an affirmative response should be made and the program issues the prompts for the new limits (Figure 9-2).

ERROR: If the resulting range is too small, the message shown at the bottom of the figure is issued and control returns to the Main Module Menu (Chapter 2, step h).

```
THE ANALYSIS OF THE DATA SET OF SIZE iii WILL (BY DEFAULT) OCCUR
BETWEEN ELEMENTS iii AND iii. ENTER ONE TO USE A DIFFERENT RANGE
OR ZERO TO USE THIS RANGE OF iii ELEMENTS.

If user override was selected, then:

  ENTER STARTING INDEX, GREATER THAN 1.
  ENTER ENDING INDEX, LESS THAN iii.

End if

**ANALYSIS CANNOT BE MADE; RANGE MUST BE AT LEAST TWO.
```

FIGURE 9-2.   ANALYSIS RANGE SPECIFICATION

c.   Transfer to the Indicated Analysis

SMERFS then transfers control to Paragraph 9.2.1 if execution time data are resident, or Paragraph 9.2.2 if interval data are resident.

9.2.1 Applicability Analysis for Execution Time Data

If execution time data are resident (data type was entered as a one, two, or three), then:

a.   The program prompts the user to enter the type of analysis to be performed (Figure 9-3). If an invalid option number is entered, the same list and second prompt are output. (Refer to Section 9.3 for descriptions of these analyses.)

NOTE: During the execution of these analyses, it is not necessary to record the values for the various statistics, as a summary table of those values will be scripted when an eight is entered for the model applicability option number.

```
ENTER MODEL APPLICABILITY ANALYSIS OPTION, OR ZERO FOR A LIST.
THE AVAILABLE MODEL APPLICABILITY ANALYSIS OPTIONS ARE:
  1 THE MODEL ACCURACY STATISTIC
  2 THE MODEL ACCURACY STATISTIC AND SCATTER PLOT
  3 THE MODEL BIAS STATISTIC AND U-PLOT
  4 THE MODEL BIAS STATISTIC, U-PLOT, AND SCATTER PLOT
  5 THE MODEL NOISE STATISTIC
  6 THE MODEL TREND STATISTIC AND Y-PLOT
  7 FULL ANALYSIS WITH SUMMARY REPORT ONLY PRINTOUT
  8 RETURN TO THE MAIN PROGRAM
ENTER MODEL APPLICABILITY ANALYSIS OPTION.
```

FIGURE 9-3. EXECUTION TIME MODEL APPLICABILITY MENU

b.   The program then prompts for a flag indicating if all execution time models are to be
executed (Figure 9-4). If the execution of all models is desired, enter zero. Otherwise, if
the selection of certain models is desired, then an affirmative response should be made and
the program will allow the user to chose the models to be executed.

```
    ENTER ONE TO SELECT THE MODELS, OR ZERO TO RUN ALL SEVEN.

If user specification was selected, then:

    ENTER ONE FOR GEOMETRIC MODEL; ELSE ZERO.
    ENTER ONE FOR JELINSKI/MORANDA MODEL; ELSE ZERO.
    ENTER ONE FOR LITTLEWOOD AND VERRALL-LIN  MODEL; ELSE ZERO.
    ENTER ONE FOR LITTLEWOOD AND VERRALL-QUAD MODEL; ELSE ZERO.
    ENTER ONE FOR MUSA BASIC EXECUTION TIME MODEL; ELSE ZERO.
    ENTER ONE FOR MUSA LOG POISSON EXE. TIME MODEL;  ELSE ZERO.
    ENTER ONE FOR NHPP MODEL FOR TBF DATA; ELSE ZERO.

End if
```

FIGURE 9-4. EXECUTION TIME MODEL SELECTION PROMPTS

c.   If the entered model applicability option number is one, SMERFS outputs the computed
statistics for the Accuracy of the model predictions (along with alphabetic labels to identify
the models) (Figure 9-5). Upon completion, control returns to step a.

ERROR: If any execution of the model in the range of iterations defined in Section 9.2,
step b failed to achieve the convergence criteria, the analysis for that model is
ended and the error message shown at the bottom of the figure is issued.

```
    THE FOLLOWING WERE DETERMINED BASED ON iii POINTS

Do for each of the specified models:

 If the execution was successful, then:

  aaaaaaaaaaaaaaaaaaaaaaaaaaaa STATISTIC IS  eeeeeeeeeeeee

 Else, if the execution was not successful, then:

 **aaaaaaaaaaaaaaaaaaaaaaaaaaa FAILED RFLAG  i ON ITER. iii (OBS. iii)

 End if

 End do
```

FIGURE 9-5. MODEL ACCURACY STATISTIC PRINTOUT

d.   If the entered model applicability option number is two, SMERFS performs the same processing as described in step c; however, the individual values used to define the statistic are also plotted (Figure 9-6). Upon completion, control returns to step a.

The plotter can only reflect a maximum of 50 elements on the x-axis. The messages shown at the bottom of the figure not only provide for a pause between plots, but also allow for termination of the plotting.

NOTE: The minimum and maximum values for the y-axis are defined over all values to be plotted, not just those reflected in the plot of 50 points.
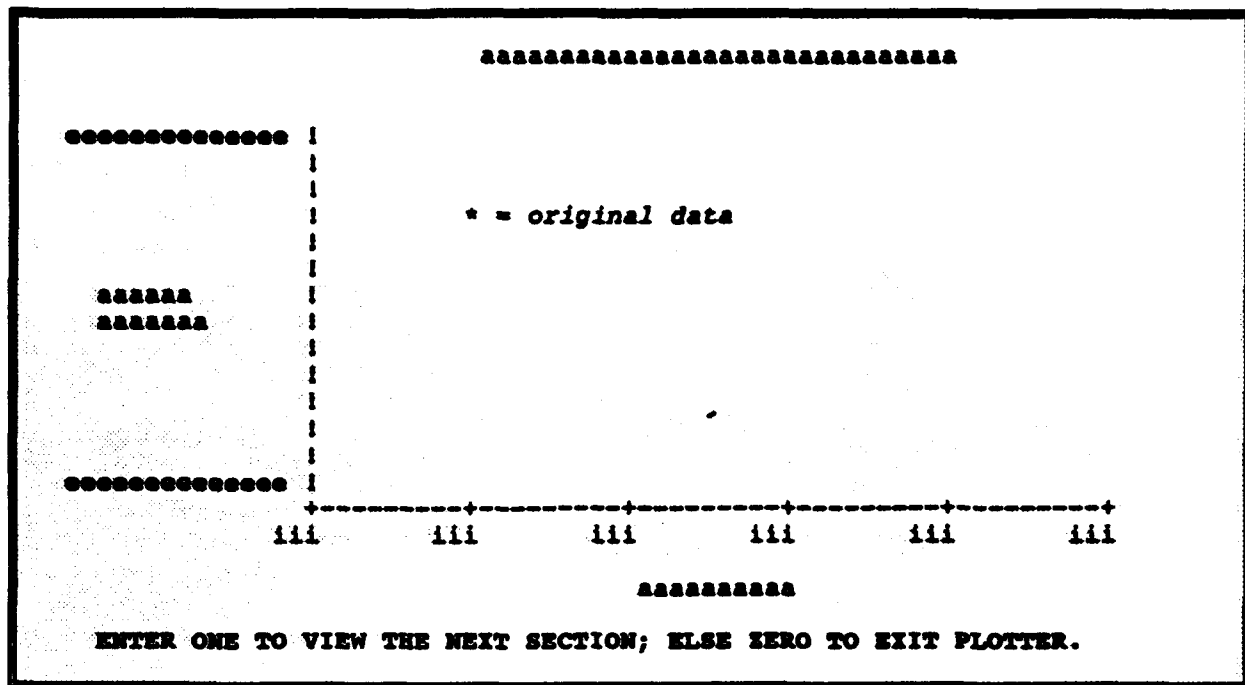
```
 eeeeeeeeeeeeee I
                I
                I
                I            *  = computed value
                I
                I
                I
                I
                I
                I
                I
                I
                I
                I
 eeeeeeeeeeeeee I
                +---------+---------+---------+---------+---------+
      iii       iii       iii       iii       iii       iii

  ENTER ONE TO VIEW THE NEXT SECTION; ELSE ZERO TO EXIT PLOTTER.
  ENTER ONE TO CONTINUE THE PROCESSING.
```
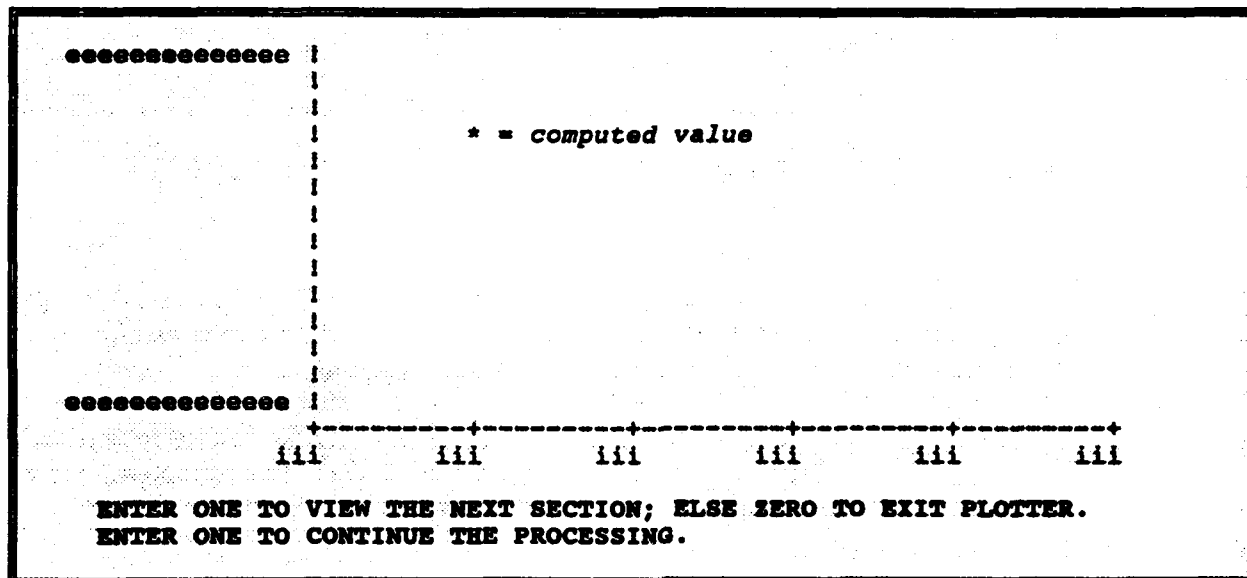
FIGURE 9-6. MODEL ACCURACY SCATTER PLOT

e.   If the entered model applicability option number is three, SMERFS outputs the computed statistics for the Bias of the model predictions and the corresponding U-Plot (along with alphabetic labels to identify the models) (Figure 9-7). Upon completion, control returns to step a.

ERROR: If any execution of the model in the range of iterations defined in Section 9.2, step b failed to achieve the convergence criteria, the analysis for that model is ended and the error message shown at the bottom of the figure is issued.

```
Do for each of the specified models:

If the execution was successful, then:

                U-PLOT FOR aaaaaaaaaaaaaaaaaaaaaaaaaaaaa
                KOLMOGOROV DISTANCE IS   eeeeeeeeeeeeeee
                BASED ON iii OF iii POINTS

   1 I
     I
     I
     I
     I        * = 0,0 to 1,1 line
     I        U = computed value
     I        $ = * and U too close to distinguish on plot
     I
     I
     I
     I
     I
     I
     I
   0 +----------+----------+----------+----------+----------+----------+
     0                     1/NS WITH A STEP OF i

   ENTER ONE TO CONTINUE THE PROCESSING.

Else, if the execution was not successful, then:

**aaaaaaaaaaaaaaaaaaaaaaaaaaaaaa FAILED RFLAG  i ON ITER. iii (OBS. iii)

End if

End do
```
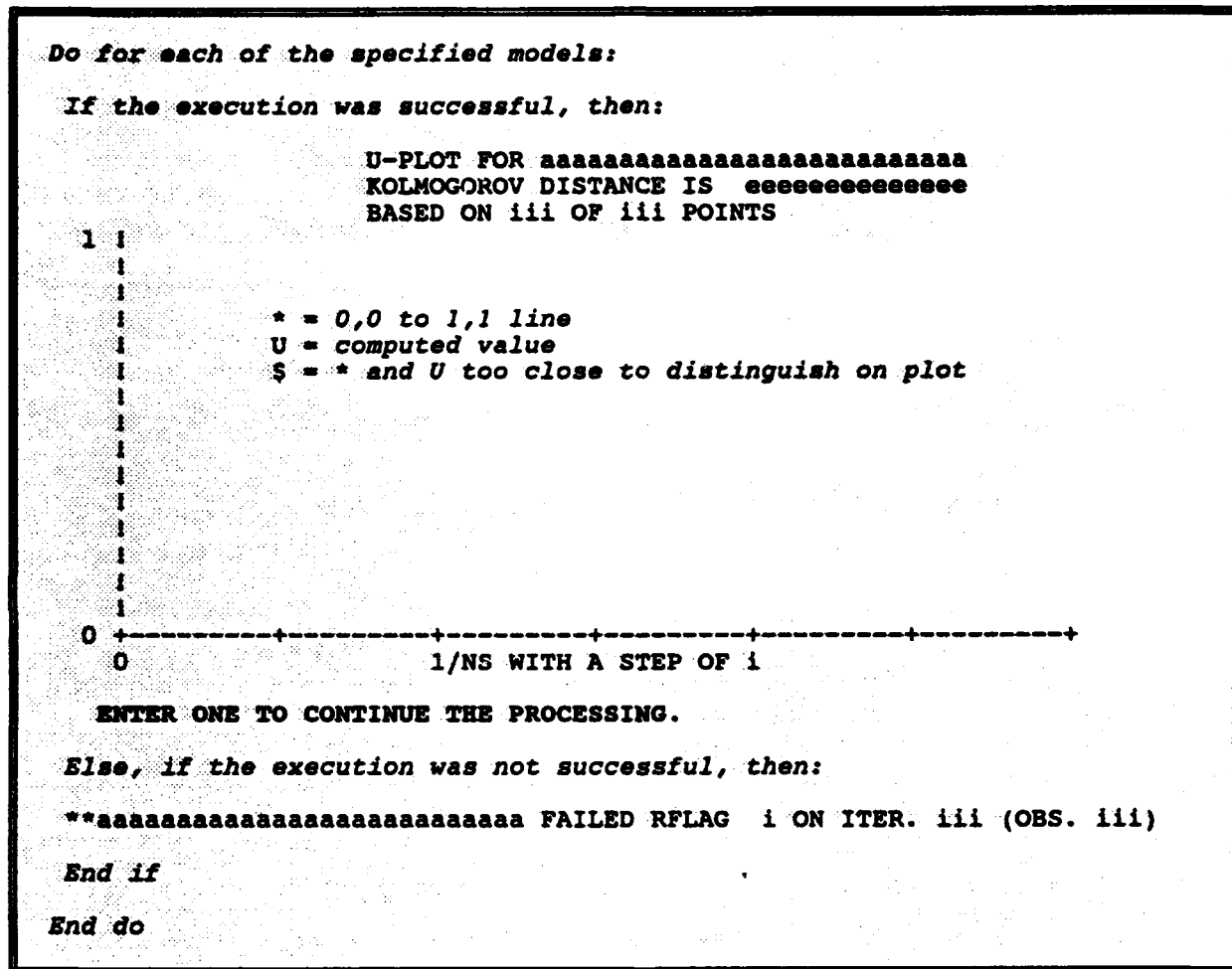
FIGURE 9-7. MODEL BIAS STATISTIC PRINTOUT AND U-PLOT

f.   If the entered model applicability option number is four, SMERFS performs the same processing and displays the same data as described in step e; however, the unsorted values from the Y-Plot are also plotted through a plot similar to that described in step d. Upon completion, control returns to step a.

g. If the entered model applicability option number is five, SMERFS outputs the computed statistics for the Noise of the model predictions using the same report format as shown in Figure 9-5. Upon completion, control returns to step a.

ERROR: If any execution of the model in the range of iterations defined in Section 9.2, step b failed to achieve the convergence criteria, the analysis for that model is ended and the error message shown at the bottom of the figure is issued.

h. If the entered model applicability option number is six, SMERFS outputs the computed statistics for the Trend of the model predictions and the corresponding Y-Plot (along with alphabetic labels to identify the models) (Figure 9-8). Upon completion, control returns to step a.

ERROR: If any execution of the model in the range of iterations defined in Section 9.2, step b failed to achieve the convergence criteria, the analysis for that model is ended and the error message shown at the bottom of the figure is issued.

```
Do for each of the specified models:

If the execution was successful, then:

                Y-PLOT FOR aaaaaaaaaaaaaaaaaaaaaaaaaaaa
                KOLMOGOROV DISTANCE IS  eeeeeeeeeeeeeee
                BASED ON iii OF iii POINTS
  1 I
    I
    I
    I
    I       * = 0,0 to 1,1 line
    I       Y = computed value
    I       $ = * and Y too close to distinguish on plot
    I
    I
    I
    I
    I
    I
    I
    I
    I
    I
  0 +----------+----------+----------+----------+----------+
    0                   1/NS WITH A STEP OF i

  ENTER ONE TO CONTINUE THE PROCESSING.

Else, if the execution was not successful, then:

**aaaaaaaaaaaaaaaaaaaaaaaaaaaa FAILED RFLAG  i ON ITER. iii (OBS. iii)

End if

End do
```

FIGURE 9-8. MODEL TREND STATISTIC PRINTOUT AND Y-PLOT

i. If the entered model applicability option number is seven, SMERFS computes the statistics for the Accuracy, Bias, Noise, and Trend of the model predictions for each selected model; however, the only output are lines indicating which of the four analyses is being performed and which, if any, of the models failed to achieve the convergence criteria (Figure 9-9). No printout of the successful models will be listed. Upon completion, control continues with step j.

NOTE: Since the convergence criteria are the same for all four analyses, models which failed for the first analysis will not be attempted for the other three analyses.

```
   CURRENTLY WORKING ON THE MODEL ACCURACY ANALYSIS.

If the execution was not successful, then:

**aaaaaaaaaaaaaaaaaaaaaaaaaaa FAILED RFLAG  i ON ITER. iii (OBS. iii)

End if


   CURRENTLY WORKING ON THE MODEL BIAS ANALYSIS.

If the execution from the accuracy analysis was not successful, then:

**aaaaaaaaaaaaaaaaaaaaaaaaaaa SKIPPED BECAUSE OF PRIOR FAILURE

End if


   CURRENTLY WORKING ON THE MODEL NOISE ANALYSIS.

If the execution from the accuracy analysis was not successful, then:

**aaaaaaaaaaaaaaaaaaaaaaaaaaa SKIPPED BECAUSE OF PRIOR FAILURE

End if


   CURRENTLY WORKING ON THE MODEL TREND ANALYSIS.

If the execution from the accuracy analysis was not successful, then:

**aaaaaaaaaaaaaaaaaaaaaaaaaaa SKIPPED BECAUSE OF PRIOR FAILURE

End if
```

FIGURE 9-9. FULL APPLICABILITY ANALYSIS MESSAGES

j. If the entered model applicability option number is eight (or if the option was entered as a seven and the processing is completed), SMERFS computes the rankings of the models for each of the analyses, as well as the overall ranking (based on a linear average of all of the analyses). A table of the results is then output (Figure 9-10) and control returns to the Main Module Menu (Chapter 2, step h).

```
THE FOLLOWING TABLE SUMMARIZES THE PERFORMED MODEL APPLICABILITY
ANALYSIS.  ZEROS UNDER THE VALUES PORTION INDICATE THE MODEL WAS
EITHER NOT RUN OR FAILED PRIOR TO COMPLETION. THE INTEGER NUMBER
TO THE RIGHT OF THE VALUE REFLECTS THE RANKING. THE VALUE TO THE
FAR RIGHT REPRESENTS THE AVERAGE RANKING OF EACH MODEL.

MODEL   ACCURACY/RANK   BIAS/RANK      NOISE/RANK     TREND/RANK     AVG
=====   =============   =============  =============  =============  ===

GEO     ●●●●●●●●●● i    ●●●●●●●●●● i    ●●●●●●●●●● i    ●●●●●●●●●● i    fff
JAM     ●●●●●●●●●● i    ●●●●●●●●●● i    ●●●●●●●●●● i    ●●●●●●●●●● i    fff
LAV-L   ●●●●●●●●●● i    ●●●●●●●●●● i    ●●●●●●●●●● i    ●●●●●●●●●● i    fff
LAV-Q   ●●●●●●●●●● i    ●●●●●●●●●● i    ●●●●●●●●●● i    ●●●●●●●●●● i    fff
MUS-B   ●●●●●●●●●● i    ●●●●●●●●●● i    ●●●●●●●●●● i    ●●●●●●●●●● i    fff
MUS-L   ●●●●●●●●●● i    ●●●●●●●●●● i    ●●●●●●●●●● i    ●●●●●●●●●● i    fff
NPT     ●●●●●●●●●● i    ●●●●●●●●●● i    ●●●●●●●●●● i    ●●●●●●●●●● i    fff
```

FIGURE 9-10. EXECUTION TIME APPLICABILITY SUMMARY TABLE

9.2.2 Applicability Analysis for Interval Data

If interval data are resident (data type was entered as a four), then:

a. The program prompts the user to enter the type of analysis to be performed (Figure 9-11). If an invalid option number is entered, the same list and second prompt are output. (Refer to Section 9.3 for descriptions of these analyses.)

> NOTE: During the execution of these analyses, it is not necessary to record the values for the various statistics, as a summary table of those values will be scripted when a four is entered for the model applicability option number.

```
ENTER MODEL APPLICABILITY ANALYSIS OPTION, OR ZERO FOR A LIST.
THE AVAILABLE MODEL APPLICABILITY ANALYSIS OPTIONS ARE:
 1 THE MODEL ACCURACY STATISTIC
 2 THE MODEL ACCURACY STATISTIC AND SCATTER PLOT
 3 SUMMARY REPORT ONLY PRINTOUT
 4 RETURN TO THE MAIN PROGRAM
ENTER MODEL APPLICABILITY ANALYSIS OPTION.
```

FIGURE 9-11. INTERVAL DATA MODEL APPLICABILITY MENU

b. The program then prompts for a flag indicating if all interval data models are to be executed (Figure 9-12). If the execution of all models is desired, enter zero. Otherwise, if the selection of certain models is desired, then an affirmative response should be made and the program will allow the user to chose the models to be executed.

```
   ENTER ONE TO SELECT THE MODELS, OR ZERO TO RUN ALL SIX.

If user specification was selected, then:

   ENTER ONE FOR BROOKS AND MOTLEY BINOMIAL MODEL; ELSE ZERO.
   ENTER ONE FOR BROOKS AND MOTLEY POISSON  MODEL; ELSE ZERO.
   ENTER ONE FOR GENERALIZED POISSON MODEL; ELSE ZERO.
   ENTER ONE FOR NON-HOMOGENEOUS POISSON MODEL; ELSE ZERO.
   ENTER ONE FOR SCHNEIDEWIND MODEL; ELSE ZERO.
   ENTER ONE FOR S-SHAPED RELIABILITY GROWTH MODEL; ELSE ZERO.

End if
```

FIGURE 9-12. INTERVAL DATA MODEL SELECTION PROMPTS

c.   If either of the Brooks and Motley models or the Generalized Poisson model were selected to be executed, the additional values as shown in Figure 9-13 are prompted.

```
If either of the Brooks and Motley models was selected, then:

   ENTER ALPHA  (THE PROB. OF CORRECTING FAULTS, WITHOUT INSERTING
   NEW ONES) FOR THE BROOKS AND MOTLEY MODEL.

End if

If the Generalized Poisson model was selected, then:

   ENTER ALPHA (COUNT(I)**ALPHA) FOR THE GENERALIZED POISSON MODEL.

End if
```

FIGURE 9-13. INTERVAL DATA ADDITIONAL PROMPTS

d.   If the entered model applicability option number is one, SMERFS outputs the computed statistics for the Accuracy of the model predictions using the same report format as described in Paragraph 9.2.1, step c. Upon completion, control returns to step a.

ERROR: If any execution of the model in the range of iterations defined in Section 9.2, step b failed to achieve the convergence criteria, the analysis for that model is ended and the error message shown at the bottom of Figure 9-5 is issued.
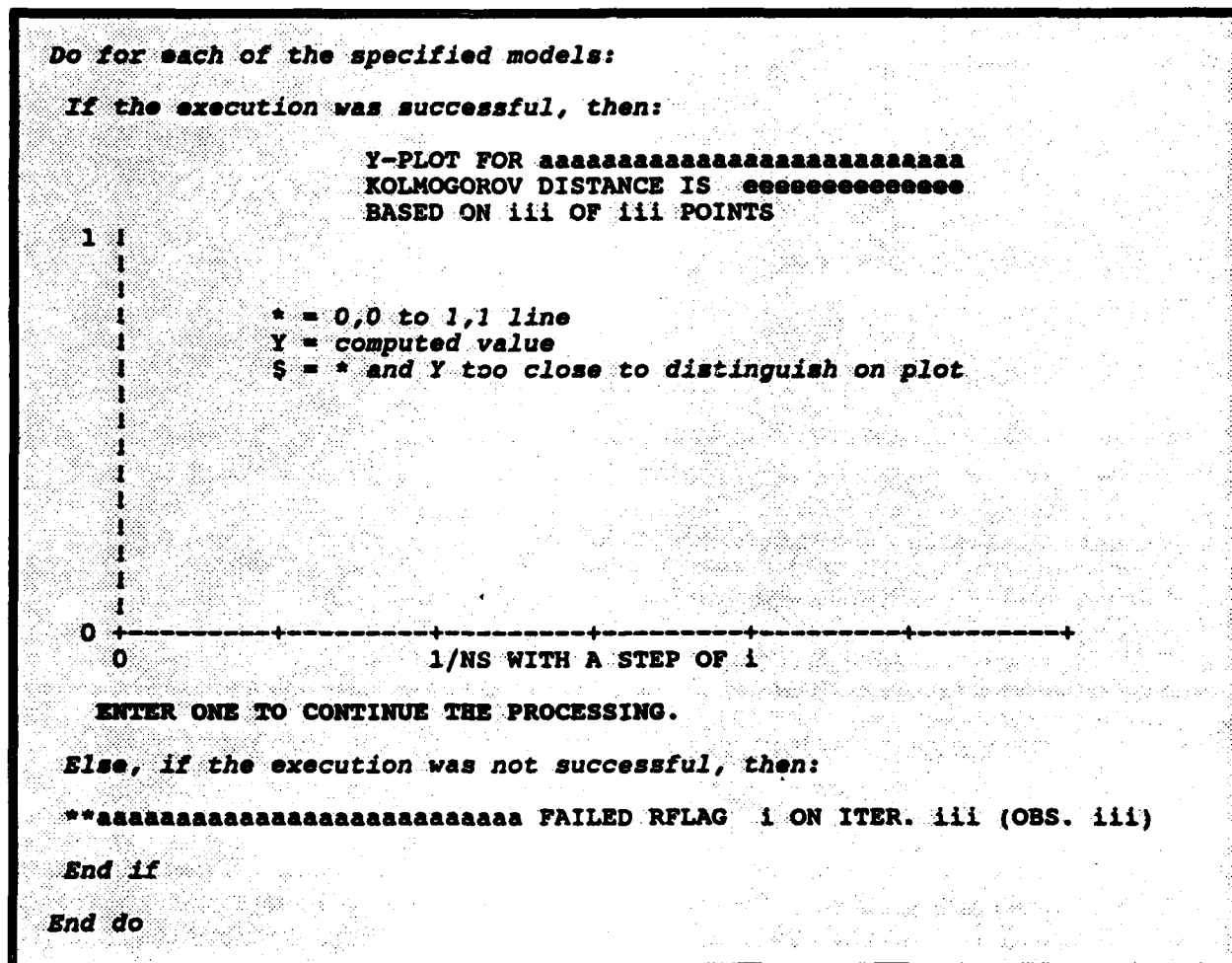
e.   If the entered model applicability option number is two, SMERFS outputs the computed statistics for the Accuracy of the model predictions and the additional plot of the values used to define the statistic using the same report format as described in Paragraph 9.2.1, step d. Upon completion, control returns to step a.

f.   If the entered model applicability option number is three, SMERFS computes the statistics for the Accuracy of the model predictions; however, the only output are lines indicating that the analysis is being performed and which, if any, of the models failed to achieve the convergence criteria (the first block of Figure 9-9). No printout of the successful models will be listed. Upon completion, control continues with step g.

g.   If the entered model applicability option number is four (or if the option was entered as a three and the processing is completed), SMERFS computes the rankings of the models for the analysis. A table of the results is then output (Figure 9-14) and control returns to the Main Module Menu (Chapter 2, step h).

```
THE FOLLOWING TABLE SUMMARIZES THE PERFORMED MODEL APPLICABILITY
ANALYSIS.  ZEROS UNDER THE VALUES PORTION INDICATE THE MODEL WAS
EITHER NOT RUN OR FAILED PRIOR TO COMPLETION. THE INTEGER NUMBER
TO THE RIGHT OF THE VALUE REFLECTS THE RANKING.


MODEL   ACCURACY/RANK
=====   =============


BAM-B   ●●●●●●●●●●● 1
BAM-P   ●●●●●●●●●●● 1
GPM     ●●●●●●●●●●● 1
MPI     ●●●●●●●●●●● 1
SDW     ●●●●●●●●●●● 1
SSH     ●●●●●●●●●●● 1
```

FIGURE 9-14. INTERVAL DATA APPLICABILITY SUMMARY TABLE

9.3 ANALYSIS OUTPUTS AND CONSIDERATIONS

The bases of the four methods are described in detail in References 5 and 6. For the Accuracy analysis, one is looking for the "best" model in forecasting future values of the time to next failure using the past failures and the negative of the prequential likelihood function. The bigger this number is, the "higher" the likelihood is that the future data points came from a given model's probability density function. Thus, the model with the largest number appears "best" using this criteria.

The Bias plot is looking for departures of the model in terms of underpredicting, overpredicting, or some functional combination of the two for future values of the time to next failure. If there is no "bias" in the model, the U_i's should be uniformly distributed over the interval zero to one; and hence, the U-plot should show the values falling along the line $y=x$. The Kolmogorov distance is a measure of the discrepancy between the U-values and this line. If this statistic is too large in relationship to the value taken from a Kolmogorov-Smirnov (K-S) one sample table, it could be concluded that the U_i's are not random. Thus, the model would then appear to have a bias within it for prediction purposes. If the U_i's are consistently above the line $y=x$, the model is overpredicting the times to next failures. Conversely, if the U_i's are consistently below the line, the predictions are too low. For this criteria, one looks for models with no Bias (i.e., that pass the K-S test for uniformity).

In some models, the predictions may be too high (low) early on and then too low (high) in later stages. This will cause the model to appear to be "unbiased" using the U-plots. The Trend plot (Y-plot) eliminates this problem as it looks also at the behavior of the statistics over time. The Trend statistics show the consistency of the model's Bias. A small value means the model is better able to adapt to changes in the behavior of the data; and hence, will tend to yield better prediction performance. Again, one is looking for the model whose Y-plot shows the y_i-values falling along the line $y = x$ and pass the K-S test for uniformity.

The Noise statistic based on the forecasted medians of the failure time distribution is used to indicate the model giving the least variable forecasts. The model having the smallest noise is thus the "most stable" for a given particular data set.

The user may prefer any one or combination of the above criteria to aid in determining candidate models for analysis. The authors warn that if a particular criteria is used be sure to consider not only the ranking provided by the SMERFS program, but also the magnitude of the statistics computed. There may be little difference in the magnitude between the model ranked number one and the lowest ranked one using a chosen criteria. The model applicability analysis is intended as only a preliminary filtering of the models. The selected models must then be further analyzed using the goodness-of-fit criteria (Chapter 12) after each model selection and execution to ultimately choose the "most-appropriate" model considering all the objectives of the modeler.

CHAPTER 10

SOFTWARE RELIABILITY EXECUTION TIME DATA MODULE

10.1 INTRODUCTION

This module explains the execution of the six software reliability models that obtain reliability estimates and predictions for execution time data. Entry of a Main module option number of eight automatically directs the program to this module if TBF data are resident (i.e., the data type was entered as a one, two, or three). Chapter 11 explains the execution of the five software reliability models that obtain reliability estimates and predictions for interval data (i.e., the data type was entered as a four).

10.2 EXECUTION FLOW

This section explains the prompts and inputs for the software reliability portion of SMERFS pertaining to TBF data. The placement of and the print in the figures conform to the strategy introduced in Sections 1.5 and 1.6.

a. Time Unit Acceptability

SMERFS indicates the units of measurement for the TBF data. If WC TBF and CPU TBF data are resident (data type was entered as a three), the units of both are listed. The user is then given the option to abort the analysis if the units are not acceptable for the model estimations and predictions (Figure 10-1). For example, if the WC TBF data are stored in seconds and the predictions are desired in hours, a one should be entered to abort the analysis and return control to the Main Module Menu (Chapter 2, step h). The data should then be converted to hours using the Unit Conversions module (Chapter 5).

```
THIS DATA ANALYSIS WILL BE PERFORMED IN UNITS CONSISTENT WITH THE
STORED DATA.   THIS MEANS THAT:

aaa TBF ESTIMATIONS AND PREDICTIONS WILL BE MADE IN aaaaaaa

ENTER ONE TO CONTINUE WITH THE ANALYSIS;   ELSE ZERO TO RETURN TO
THE MAIN MODULE MENU, SO CONVERSION CAN BE MADE BY MODULE THREE.
```

FIGURE 10-1. TIME UNIT ACCEPTABILITY MESSAGE

b. Software Reliability Model Selection

SMERFS then prompts the user to enter the desired software reliability model (Figure 10-2). If an invalid option number is entered, the same list and second prompt are output. The user response to the third prompt in the figure (which is only issued if the data type was entered as a three) is used to determine if the model execution is to be performed on WC TBF or CPU TBF data.

```
ENTER TIME MODEL OPTION, OR ZERO FOR A LIST.
THE AVAILABLE WALL CLOCK OR CPU TIME MODELS ARE:
 1 THE GEOMETRIC MODEL
 2 THE JELINSKI/MORANDA DE-EUTROPHICATION MODEL
 3 THE LITTLEWOOD AND VERRALL BAYESIAN MODEL
 4 THE MUSA BASIC EXECUTION TIME MODEL
 5 THE MUSA LOG POISSON EXECUTION TIME MODEL
 6 THE NHPP MODEL FOR TIME-BETWEEN-FAILURE OCC.
 7 RETURN TO THE MAIN PROGRAM
ENTER MODEL OPTION.

If WC TBF and CPU TBF data, then:

 ENTER ONE FOR WC TBF OR TWO FOR CPU TBF.

**DATA TYPE ERROR; TRY AGAIN (AFTER THE PROMPT).

End if
```

FIGURE 10-2. EXECUTION TIME DATA MODEL MENU

c. Transfer to the Indicated Model

If the entered model option number is seven, control returns to the Main Module Menu (Chapter 2, step h). Otherwise (if a valid model number is entered), the program transfers control to the indicated model, where:

1. The Geometric model is contained in Paragraph 10.2.1.
2. The Jelinski/Moranda model is contained in Paragraph 10.2.2.
3. The Littlewood and Verrall model is contained in Paragraph 10.2.3.
4. The Musa Basic Execution Time model is contained in Paragraph 10.2.4.
5. The Musa Logarithmic Poisson Execution Time model is contained in Paragraph 10.2.5.
6. The Non-homogeneous Poisson model is contained in Paragraph 10.2.6.

10.2.1 Geometric Model

If the entered model option number is one, then:

a. SMERFS prompts for a flag indicating whether the model assumptions and data requirements are desired (Figure 10-3). If desired, the listing and extra prompt in the figure are output. If the response to the last prompt indicates a desire to abort the model execution, control returns to Section 10.2, step b. (Refer to Paragraph 10.3.1 for details on the generated output.)

```
ENTER ONE FOR GEOMETRIC MODEL DESCRIPTION; ELSE ZERO.

THE GEOMETRIC MODEL ASSUMPTIONS

  1. THE SOFTWARE IS OPERATED IN A SIMILAR MANNER AS THE ANTICI-
     PATED OPERATIONAL USAGE.

  2. ALL FAULTS ARE EQUALLY LIKELY TO OCCUR  AND ARE INDEPENDENT
     OF EACH OTHER.

  3. THE FAULT DETECTION RATE FORMS A GEOMETRIC  PROGRESSION AND
     IS CONSTANT BETWEEN FAULT OCCURRENCES.

  4. THERE IS AN INFINITE NUMBER OF TOTAL FAULTS (I.E., THE PRO-
     GRAM WILL NEVER BE FAULT-FREE).

MODEL DATA REQUIREMENTS

  1. THE TIME-BETWEEN-FAILURES AS MEASURED IN WALL CLOCK OR COM-
     PUTER CPU TIME.  THE DATA SHOULD HAVE  BEEN ENTERED VIA THE
     INPUT MODULE.

IF THE ASSUMPTIONS ARE  GENERALLY SATISFIED AND THE APPROPRIATE
DATA ARE AVAILABLE, ENTER ONE TO CONTINUE THE MODEL;  OTHERWISE
ZERO TO RETURN TO THE MENU OF MODELS.
```

FIGURE 10-3. MDLGEO DESCRIPTION PROMPTS AND LIST

b. SMERFS prompts the user to enter the desired method of estimation [Maximum Likelihood (ML) or Least Squares (LS)] or a value to terminate this model execution (Figure 10-4). If the termination value is entered, control branches to step f.

```
ENTER ONE FOR  MAXIMUM LIF.  HOOD METHOD,  TWO FOR LEAST SQUARES
METHOD, OR THREE TO TERMI....E MODEL EXECUTION.
```

FIGURE 10-4. MDLGEO INPUT PROMPT

c. If the data are not appropriate for this model, then the message shown in Figure 10-5 (including the ML or LS indicator) is issued and control returns to step b.

```
**THE DATA ARE NOT APPROPRIATE FOR THE aa MODEL.
```

FIGURE 10-5. MDLGEO PROCESSING ERROR MESSAGE

d. Otherwise (if the solution is obtained), the ML or LS estimates are output (Figure 10-6). Within that figure, the upper report (containing the 95-percent confidence intervals) corresponds to the ML estimates and the lower report to the LS estimates.

```
If the ML method was selected, then:

  ML MODEL ESTIMATES ARE:
  (THE APPROXIMATE 95% CONFIDENCE INTERVALS APPEAR IN PARENTHESES)
     PROPORTIONALITY CONSTANT   eeeeeeeeee ( eeeeeeeee, eeeeeeeee)
     HAZARD RATE PARAMETER       eeeeeeeeee ( eeeeeeeee, eeeeeeeee)
     INIT. INTENSITY FUNCTION    eeeeeeeeee
     CUR.  INTENSITY FUNCTION    eeeeeeeeee
     MTBNF                       eeeeeeeeee ( eeeeeeee, eeeeeeeee)
     PURIFICATION LEVEL          eeeeeeeeee ( eeeeeeeee, eeeeeeeee)

Else, If the LS method was selected, then:

  LS MODEL ESTIMATES ARE:
     PROPORTIONALITY CONSTANT   eeeeeeeeee
     HAZARD RATE PARAMETER       eeeeeeeeee
     INIT. INTENSITY FUNCTION    eeeeeeeeee
     CUR.  INTENSITY FUNCTION    eeeeeeeeee
     MTBNF                       eeeeeeeeee
     PURIFICATION LEVEL          eeeeeeeeee

End if
```

FIGURE 10-6. MDLGEO SUCCESSFUL CONVERGENCE OUTPUT

e. SMERFS then allows for the processing of future predictions to determine the expected performance of the software (Figure 10-7). Upon completion, control returns to step b.

ERROR: If the estimate for the MTBNF is negative, these future predictions are not allowed and the message shown at the bottom of the figure is issued.

```
    THE AVAILABLE FUTURE PREDICTIONS ARE:
     1) THE TOTAL MTBNF FOR THE NEXT K FAILURES
     2) THE TIME AND NUMBER OF FAILURES TO REACH A DESIRED INTENSITY
        FUNCTION
     3) THE NUMBER OF FAILURES EXPECTED IN A SPECIFIED TIME
    ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.

     ENTER VALUE OF K, OR ZERO TO END.
     MTBNF EXPECTED            eeeeeeeeee

     ENTER INTENSITY FUNC. (LESS THAN eeeeeeeeee), OR ZERO TO END.
     ADDITIONAL TESTING TIME  eeeeeeeeee
     # OF FAILURES EXPECTED    eeeeeeeeee

     ENTER LENGTH OF THE PERIOD, OR ZERO TO END.
     # OF FAILURES EXPECTED    eeeeeeeeee

  **FUTURE PREDICTIONS ARE NOT ALLOWED  BECAUSE THE ESTIMATE FOR THE
    MTBNF IS LESS THAN ZERO.
```

FIGURE 10-7. MDLGEO FUTURE PREDICTION PROMPTS AND OUTPUT

f.   The user has responded to the prompt in step b with a value equated to termination. Before
      the return is performed, SMERFS determines if the last execution for either of the methods
      of estimation was successful; if either was, it allows for various analyses of the model fit.
      This is shown in the first prompt of Figure 10-8. Additionally, if both the ML and LS
      methods were successful, the second prompt is issued, allowing the user to select the set of
      estimates to be used in the analyses. Control then automatically transfers to the Analyses
      of Model Fit sub-module (Chapter 12). Upon completion, control returns to the Execution
      Time Data Model Menu (Section 10.2, step b).

```
    ENTER ONE TO PERFORM AN ANALYSIS OF THE MODEL FIT USING THE PRE-
    DICTIONS OF THIS MODEL; ELSE ZERO.

  If ML and LS were successful, then:

    ENTER ONE FOR PREDICTIONS BASED ON MAXIMUM LIKELIHOOD METHOD, OR
    TWO FOR LEAST SQUARES METHOD.

  End if
```

FIGURE 10-8. MDLGEO ANALYSES OF MODEL FIT PROMPTS

10.2.2 Jelinski/Moranda De-Eutrophication Model

If the entered model option number is two, then:

a.   SMERFS prompts for a flag indicating whether the model assumptions and data requirements are desired (Figure 10-9). If desired, the listing and extra prompts in the figure are output. If the response to the last prompt indicates a desire to abort the model execution, control returns to Section 10.2, step b. (Refer to Paragraph 10.3.2 for details on the generated output.)

ENTER ONE FOR JELINSKI/MORANDA MODEL DESCRIPTION; ELSE ZERO.

THE JELINSKI/MORANDA "DE-EUTROPHICATION MODEL" ASSUMPTIONS

 1. THE SOFTWARE IS OPERATED IN A SIMILAR MANNER AS THE ANTICI-
    PATED OPERATIONAL USAGE.

 2. ALL FAULTS ARE EQUALLY LIKELY TO OCCUR AND ARE INDEPENDENT
    OF EACH OTHER.

 3. EACH FAULT IS OF THE SAME ORDER OF "IMPACT" AS ANY OTHER.

 4. THE RATE OF FAULT DETECTION IS PROPORTIONAL TO THE CURRENT
    FAULT CONTENT OF A PROGRAM.

 5. THE FAILURE RATE REMAINS CONSTANT OVER THE TIME PERIOD BE-
    TWEEN FAILURE OCCURRENCES.

 6. THE FAULTS ARE CORRECTED AT THE TIME OF OCCURRENCE WITHOUT
    INTRODUCTION OF NEW ONES.

ENTER ONE TO CONTINUE THE DESCRIPTION LIST.
MODEL DATA REQUIREMENTS

 1. THE TIME-BETWEEN-FAILURES AS MEASURED IN WALL CLOCK OR COM-
    PUTER CPU TIME. THE DATA SHOULD HAVE BEEN ENTERED VIA THE
    INPUT MODULE.

IF THE ASSUMPTIONS ARE GENERALLY SATISFIED AND THE APPROPRIATE
DATA ARE AVAILABLE, ENTER ONE TO CONTINUE THE MODEL; OTHERWISE
ZERO TO RETURN TO THE MENU OF MODELS.

FIGURE 10-9. MDLJAM DESCRIPTION PROMPTS AND LIST

b.   SMERFS then prompts the user to enter the desired method of estimation (ML or LS) or a value to terminate this model execution (Figure 10-10). If the termination value is entered, control branches to step f.

```
ENTER ONE FOR  MAXIMUM LIKELIHOOD METHOD,  TWO FOR LEAST SQUARES
METHOD, OR THREE TO TERMINATE MODEL EXECUTION.
```

FIGURE 10-10. MDLJAM INPUT PROMPT

c.   If the data are not appropriate for this model or the estimate of the total number of faults is less than the observed number, then the appropriate message shown in Figure 10-11 (including the ML or LS indicator) is issued and control returns to step b.

```
**THE DATA ARE NOT APPROPRIATE FOR THE aa MODEL.

**THE ESTIMATE  FOR THE TOTAL  NUMBER OF FAULTS  TO BE DETECTED IN
  THE PROGRAM BEFORE  ALL FAULTS ARE UNCOVERED  CAME OUT LESS THAN
  THE NUMBER OF FAULTS FOUND TO DATE WITHIN THE aa MODEL.
```

FIGURE 10-11. MDLJAM PROCESSING ERROR MESSAGES

d.   Otherwise (if the solution is obtained), the ML or LS estimates are output (Figure 10-12).

```
aa MODEL ESTIMATES ARE:
  PROPORTIONALITY CONSTANT   ●●●●●●●●●●●
  INIT. INTENSITY FUNCTION   ●●●●●●●●●●●
  CUR.  INTENSITY FUNCTION   ●●●●●●●●●●●
  MTBNF                      ●●●●●●●●●●●
  TOTAL NUMBER OF FAULTS     ●●●●●●●●●●●
  # OF FAULTS REMAINING      ●●●●●●●●●●●
  PURIFICATION LEVEL         ●●●●●●●●●●●
```

FIGURE 10-12. MDLJAM SUCCESSFUL CONVERGENCE OUTPUT

e.   SMERFS then allows for the processing of future predictions to determine the expected performance of the software (Figure 10-13). Upon completion, control returns to step b.

ERROR: If the estimate for the (rounded) number of faults remaining is less than one or the MTBNF is negative, these future predictions are not allowed and the appropriate message shown at the bottom of the figure is issued.

```
THE AVAILABLE FUTURE PREDICTIONS ARE:
 1) THE EXPECTED RELIABILITY FOR A SPECIFIED TIME
 2) THE TOTAL MTBNF FOR THE NEXT K FAILURES
 3) THE TIME AND NUMBER OF FAILURES TO REACH A DESIRED INTENSITY
    FUNCTION
 4) THE NUMBER OF FAILURES EXPECTED IN A SPECIFIED TIME
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.

 ENTER LENGTH OF THE PERIOD, OR ZERO TO END.
 FUTURE RELIABILITY         eeeeeeeeeee

 ENTER VALUE OF K, OR ZERO TO END.
 MTBNF EXPECTED             eeeeeeeeeee

 ENTER INTENSITY FUNC. (LESS THAN eeeeeeeeeee), OR ZERO TO END.
 ADDITIONAL TESTING TIME    eeeeeeeeeee
 # OF FAILURES EXPECTED     eeeeeeeeeee

 ENTER LENGTH OF THE PERIOD, OR ZERO TO END.
 # OF FAILURES EXPECTED     eeeeeeeeeee

**FUTURE PREDICTIONS ARE NOT ALLOWED  BECAUSE THE ESTIMATE FOR THE
 (ROUNDED) NUMBER OF FAULTS REMAINING IS LESS THAN ONE.

**FUTURE PREDICTIONS ARE NOT ALLOWED  BECAUSE THE ESTIMATE FOR THE
 MTBNF IS LESS THAN ZERO.
```

FIGURE 10-13. MDLJAM FUTURE PREDICTION PROMPTS AND OUTPUT

f.   The user has responded to the prompt in step b with a value equated to termination. Before the return is performed, SMERFS determines if the last execution for either of the methods of estimation was successful; if either was, it allows for various analyses of the model fit. This is shown in the first prompt of Figure 10-14. Additionally, if both the ML and LS methods were successful, the second prompt is issued, allowing the user to select the set of estimates to be used in the analyses. Control then automatically transfers to the Analyses of Model Fit sub-module (Chapter 12). Upon completion, control returns to the Execution Time Data Model Menu (Section 10.2, step b).

```
 ENTER ONE TO PERFORM AN ANALYSIS OF THE MODEL FIT USING THE PRE-
 DICTIONS OF THIS MODEL; ELSE ZERO.

If ML and LS were successful, then:

 ENTER ONE FOR PREDICTIONS BASED ON MAXIMUM LIKELIHOOD METHOD, OR
 TWO FOR LEAST SQUARES METHOD.

End if
```

FIGURE 10-14. MDLJAM ANALYSES OF MODEL FIT PROMPTS

10.2.3 Littlewood and Verrall's Bayesian Reliability Growth Model

If the entered model option number is three, then:

a. SMERFS prompts for a flag indicating whether the model assumptions and data requirements are desired (Figure 10-15). If desired, the listing and extra prompts in the figure are output. If the response to the last prompt indicates a desire to abort the model execution, control returns to Section 10.2, step b. (Refer to Paragraph 10.3.3 for details on the prompted input and generated output.)

```
ENTER ONE FOR LITTLEWOOD & VERRALL MODEL DESCRIPTION; ELSE ZERO.

THE LITTLEWOOD & VERRALL BAYESIAN MODEL ASSUMPTIONS

  1. THE SOFTWARE IS OPERATED IN A SIMILAR MANNER AS THE ANTICI-
     PATED OPERATIONAL USAGE.

  2. SUCCESSIVE TIME-BETWEEN-FAILURES ARE INDEPENDENT RANDOM
     VARIABLES EACH HAVING AN EXPONENTIAL DISTRIBUTION. THE DIS-
     TRIBUTION FOR THE I-TH FAILURE HAS A MEAN OF 1/LAMDA(I).

  3. THE LAMDA(I) FORM A SEQUENCE OF INDEPENDENT VARIABLES, EACH
     HAVING A GAMMA DISTRIBUTION WITH THE PARAMETERS ALPHA AND
     PHI(I). PHI(I) HAS EITHER THE FORM:

     BETA(0) + BETA(1) * I      (LINEAR)
     OR
     BETA(0) + BETA(1) * I**2   (QUADRATIC).

ENTER ONE TO CONTINUE THE DESCRIPTION LIST.
MODEL DATA REQUIREMENTS

  1. THE TIME-BETWEEN-FAILURES AS MEASURED IN WALL CLOCK OR COM-
     PUTER CPU TIME.  THE DATA SHOULD HAVE  BEEN ENTERED VIA THE
     INPUT MODULE.

IF THE ASSUMPTIONS ARE  GENERALLY SATISFIED AND THE APPROPRIATE
DATA ARE AVAILABLE, ENTER ONE TO CONTINUE THE MODEL;  OTHERWISE
ZERO TO RETURN TO THE MENU OF MODELS.
```

FIGURE 10-15. MDLLAV DESCRIPTION PROMPTS AND LIST

b. SMERFS then prompts the user to enter the desired method of estimation (ML or LS) or a value to terminate this model execution (Figure 10-16). If the termination value is entered, control branches to step f. If a method of estimation is selected, then SMERFS prompts for the desired function number (indicating either linear or quadratic). For the LS method, no additional inputs are required. For the ML method, the initial estimates for BETA are obtained from the LS method. Those values are then output (Figure 10-16) and SMERFS allows the user to override the values to ensure the global maximum has been reached. Lastly, the program prompts for the maximum number of convergence iterations.

ENTER ONE FOR MAXIMUM LIKELIHOOD METHOD, TWO FOR LEAST SQUARES
METHOD, OR THREE TO TERMINATE MODEL EXECUTION.

WHICH FUNCTION IS DESIRED TO BE USED AS THE PHI(I) IN THE GAMMA
DISTRIBUTION? GAMMA IS USED AS THE PRIOR WITH PARAMETERS ALPHA
AND PHI(I)

  1. PHI(I) = BETA(0) + BETA(1) * I   (LINEAR)
OR
  2. PHI(I) = BETA(0) + BETA(1) * I**2 (QUADRATIC).

If the ML method was selected, then:

  THE INITIAL ESTIMATES TO BE USED IN THE ESTIMATION PROCESS ARE:
  BETA(0)   eeeeeeeeeee
  BETA(1)   eeeeeeeeeee

  ENTER ONE TO USE DIFFERENT INITIAL ESTIMATES, OR ZERO TO USE THE
  INITIAL ESTIMATES.

 If user override was selected, then:

  ENTER INITIAL ESTIMATES FOR BETA(0) AND BETA(1)
  (BETWEEN 0.10000E-06 AND 0.10000E+08).

 End if

  ENTER MAXIMUM NUMBER OF ITERATIONS.

End if

FIGURE 10-16. MDLLAV INPUT PROMPTS

c. If the maximum number of iterations is reached before a solution is found, the Trust Region
could not be adjusted properly using the initial estimates for BETA, or the model parameters
resulted in a negative initial MTBNF, then the appropriate message shown in Figure 10-17
(including the ML or LS indicator) is issued and control returns to step b.

**THE MAXIMUM NUMBER OF ITERATIONS WAS REACHED   WITH THE FOLLOWING
  FINAL ML MODEL ESTIMATES:
  ALPHA   eeeeeeeeeee
  BETA(0)   eeeeeeeeeee
  BETA(1)   eeeeeeeeeee
  FUNCTION EVALUATED AT
   THESE POINTS   eeeeeeeeeee
  INIT. INTENSITY FUNCTION eeeeeeeeeee
  CUR. INTENSITY FUNCTION eeeeeeeeeee
  MTBNF   eeeeeeeeeee

FIGURE 10-17. MDLLAV PROCESSING ERROR MESSAGES

```
**THE TRUST REGION COULD NOT BE ADJUSTED PROPERLY IN THE ML MODEL.

**THE ESTIMATES OF THE aa MODEL PARAMETERS:
  BETA(0) eeeeeeeeee AND BETA(1) eeeeeeeeee
  RESULTED IN A NEGATIVE ESTIMATE FOR THE INITIAL MTBNF. THE MODEL
  THUS CANNOT BE APPLIED FOR THIS DATA SET.
```

FIGURE 10-17. MDLLAV PROCESSING ERROR MESSAGES (Continued)

d.   Otherwise (if the solution is obtained), the ML or LS estimates are output (Figure 10-18). Within the figure, the upper report (containing the additional ALPHA estimate and the number of iterations performed to obtain the estimates) corresponds to the ML estimates and the lower report to the LS estimates.

```
If the ML method was selected, then:

  ML MODEL ESTIMATES AFTER iii ITERATIONS ARE:
    ALPHA                       eeeeeeeeeee
    BETA(0)                     eeeeeeeeeee
    BETA(1)                     eeeeeeeeeee
    FUNCTION EVALUATED AT
     THESE POINTS               eeeeeeeeeee
    INIT. INTENSITY FUNCTION    eeeeeeeeeee
    CUR.  INTENSITY FUNCTION    eeeeeeeeeee
    MTBNF                       eeeeeeeeeee

Else, if the LS method was selected, then:

  LS MODEL ESTIMATES ARE:
    BETA(0)                     eeeeeeeeeee .
    BETA(1)                     eeeeeeeeeee
    FUNCTION EVALUATED AT
     THESE POINTS               eeeeeeeeeee
    INIT. INTENSITY FUNCTION    eeeeeeeeeee
    CUR.  INTENSITY FUNCTION    eeeeeeeeeee
    MTBNF                       eeeeeeeeeee

End if
```

FIGURE 10-18. MDLLAV SUCCESSFUL CONVERGENCE OUTPUT

e.   SMERFS then allows for the processing of future predictions to determine the expected performance of the software (Figure 10-19). Within the figure, the upper report (containing the prediction for the additional testing time and the expected number of failures to reach a desired intensity function) corresponds to the linear function and the lower report to the quadratic function. Upon completion, control returns to step b.

ERROR: If the MTBNF is negative, these future predictions are not allowed and the message shown at the bottom of the figure is issued.

```
If the Linear function was selected, then:

  THE AVAILABLE FUTURE PREDICTIONS ARE:
   1) THE TOTAL MTBNF FOR THE NEXT K FAILURES
   2) THE TIME AND NUMBER OF FAILURES TO REACH A DESIRED INTENSITY
      FUNCTION
   3) THE NUMBER OF FAILURES EXPECTED IN A SPECIFIED TIME
  ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.

   ENTER VALUE OF K, OR ZERO TO END.
   MTBNF EXPECTED              eeeeeeeeeee

   ENTER INTENSITY FUNC. (LESS THAN eeeeeeeeeee), OR ZERO TO END.
   ADDITIONAL TESTING TIME  eeeeeeeeeee
   # OF FAILURES EXPECTED    eeeeeeeeeee

   ENTER LENGTH OF THE PERIOD, OR ZERO TO END.
   # OF FAILURES EXPECTED    eeeeeeeeeee

Else, if the Quadratic function was selected, then:

  THE AVAILABLE FUTURE PREDICTIONS ARE:
   1) THE TOTAL MTBNF FOR THE NEXT K FAILURES
   2) THE NUMBER OF FAILURES EXPECTED IN A SPECIFIED TIME
  ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.

   ENTER VALUE OF K, OR ZERO TO END.
   MTBNF EXPECTED              eeeeeeeeeee

   ENTER LENGTH OF THE PERIOD, OR ZERO TO END.
   # OF FAILURES EXPECTED    eeeeeeeeeee

End if

**FUTURE PREDICTIONS ARE NOT ALLOWED  BECAUSE THE ESTIMATE FOR THE
  MTBNF IS LESS THAN ZERO.
```

FIGURE 10-19. MDLLAV FUTURE PREDICTION PROMPTS AND OUTPUT

f.   The user has responded to the prompt in step b with a value equated to termination. Before the return is performed, SMERFS determines if the last execution for either of the methods of estimation was successful; if either was, it allows for various analyses of the model fit. This is shown in the first prompt of Figure 10-20. Additionally, if both the ML and LS methods were successful, the second prompt is issued, allowing the user to select the set of estimates to be used in the analyses. Control then automatically transfers to the Analyses of Model Fit sub-module (Chapter 12). Upon completion, control returns to the Execution Time Data Model Menu (Section 10.2, step b).

ENTER ONE TO PERFORM AN ANALYSIS OF THE MODEL FIT USING THE PRE-
DICTIONS OF THIS MODEL; ELSE ZERO.

If ML and LS were successful, then:

ENTER ONE FOR PREDICTIONS BASED ON MAXIMUM LIKELIHOOD METHOD, OR
TWO FOR LEAST SQUARES METHOD.

End if

FIGURE 10-20. MDLLAV ANALYSES OF MODEL FIT PROMPTS

10.2.4 Musa's Execution Time Model

If the entered model option number is four, then:

a. SMERFS prompts for a flag indicating whether the model assumptions and data requirements are desired (Figure 10-21). If desired, the listing and extra prompts in the figure are output. If the response to the last prompt indicates a desire to abort the model execution, control returns to Section 10.2, step b. (Refer to Paragraph 10.3.4 for details on the prompted input and generated output.)

ENTER ONE FOR MUSA (BASIC) MODEL DESCRIPTION; ELSE ZERO.

THE MUSA BASIC EXECUTION TIME MODEL ASSUMPTIONS

  1. THE SOFTWARE IS OPERATED IN A SIMILAR MANNER AS THE ANTICI-
     PATED OPERATIONAL USAGE.

  2. ALL FAULTS ARE EQUALLY LIKELY TO OCCUR AND ARE INDEPENDENT
     OF EACH OTHER.

  3. ALL SOFTWARE FAULTS ARE OBSERVED.

  4. THE EXECUTION TIMES (MEASURED IN CPU TIME) BETWEEN FAILURES
     ARE PIECEWISE EXPONENTIALLY DISTRIBUTED.

  5. THE INTENSITY FUNCTION IS PROPORTIONAL TO THE NUMBER OF
     FAULTS REMAINING IN THE PROGRAM.

  6. THE FAULT CORRECTION RATE IS PROPORTIONAL TO THE FAILURE
     OCCURRENCE RATE.

ENTER ONE TO CONTINUE THE DESCRIPTION LIST.
MODEL DATA REQUIREMENTS

  1. THE TIME-BETWEEN-FAILURES AS MEASURED IN COMPUTER CPU TIME.
     THE DATA SHOULD HAVE BEEN ENTERED VIA THE INPUT MODULE.

IF THE ASSUMPTIONS ARE GENERALLY SATISFIED AND THE APPROPRIATE
DATA ARE AVAILABLE, ENTER ONE TO CONTINUE THE MODEL; OTHERWISE
ZERO TO RETURN TO THE MENU OF MODELS.

FIGURE 10-21. MDLMUS DESCRIPTION PROMPTS AND LIST

b. If the data are not appropriate for this model or the estimate of the total number of faults is less than the observed number, then the appropriate message shown in Figure 10-22 is issued and control branches to step g.

```
**THE DATA ARE NOT APPROPRIATE FOR THE MODEL.

**THE ESTIMATE  FOR THE TOTAL  NUMBER OF FAULTS  TO BE DETECTED IN
  THE PROGRAM BEFORE  ALL FAULTS ARE UNCOVERED  CAME OUT LESS THAN
  THE NUMBER OF FAULTS FOUND TO DATE WITHIN THE MODEL.
```

FIGURE 10-22. MDLMUS PROCESSING ERROR MESSAGES

c.   Otherwise (if the solution is obtained), the ML estimates are output (Figure 10-23).

```
THE MAXIMUM LIKELIHOOD ESTIMATES ARE:
(THE APPROXIMATE 95% CONFIDENCE INTERVALS APPEAR IN PARENTHESES)
 INIT. INTENSITY FUNCTION    eeeeeeeeeee
 CUR.  INTENSITY FUNCTION    eeeeeeeeeee
 INIT. MTBNF                 eeeeeeeeeee ( eeeeeeeeee, eeeeeeeeee)
 CUR.  MTBNF                 eeeeeeeeeee
 TOTAL NUMBER OF FAULTS      eeeeeeeeeee ( eeeeeeeeee, eeeeeeeeee)
 # OF FAULTS REMAINING       eeeeeeeeeee ( eeeeeeeeee, eeeeeeeeee)
 PURIFICATION LEVEL          eeeeeeeeeee
```

FIGURE 10-23. MDLMUS SUCCESSFUL CONVERGENCE OUTPUT

d.   SMERFS then allows for the processing of future predictions to determine the expected performance of the software (Figure 10-24).

ERROR: If the estimate for the (rounded) number of faults remaining is less than one or the MTBNF is negative, these future predictions are not allowed and the appropriate message shown at the bottom of the figure is issued.

```
THE AVAILABLE FUTURE PREDICTIONS ARE:
 1) THE EXPECTED RELIABILITY FOR A SPECIFIED TIME
 2) THE TOTAL MTBNF FOR THE NEXT K FAILURES
 3) THE TIME AND NUMBER OF FAILURES TO REACH A DESIRED INTENSITY
    FUNCTION
 4) THE TIME AND NUMBER OF FAILURES TO REACH A DESIRED MTBNF
 5) THE NUMBER OF FAILURES EXPECTED IN A SPECIFIED TIME
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.

ENTER LENGTH OF THE PERIOD, OR ZERO TO END.
FUTURE RELIABILITY          eeeeeeeeeee
```

FIGURE 10-24. MDLMUS FUTURE PREDICTION PROMPTS AND OUTPUT

```
ENTER VALUE OF K (BETWEEN ONE AND ●●●●●●●●●●●), OR ZERO TO END.
MTBNF EXPECTED                ●●●●●●●●●●

ENTER INTENSITY FUNC. (LESS THAN ●●●●●●●●●●), OR ZERO TO END.
ADDITIONAL TESTING TIME  ●●●●●●●●●●
# OF FAILURES EXPECTED     ●●●●●●●●●●

ENTER DESIRED MTBNF (GREATER THAN ●●●●●●●●●●), OR ZERO TO END.
ADDITIONAL TESTING TIME  ●●●●●●●●●●
# OF FAILURES EXPECTED     ●●●●●●●●●●

ENTER LENGTH OF THE PERIOD, OR ZERO TO END.
# OF FAILURES EXPECTED   ●●●●●●●●●●

**FUTURE PREDICTIONS ARE NOT ALLOWED  BECAUSE THE ESTIMATE FOR THE
  (ROUNDED) NUMBER OF FAULTS REMAINING IS LESS THAN ONE.

**FUTURE PREDICTIONS ARE NOT ALLOWED  BECAUSE THE ESTIMATE FOR THE
  MTBNF IS LESS THAN ZERO.
```

FIGURE 10-24. MDLMUS FUTURE PREDICTION PROMPTS AND OUTPUT (Continued)

e. SMERFS then prompts for a flag indicating whether the Calendar Time Component of the
    main model is desired (Figure 10-25). If desired, a second prompt is issued to determine
    if the assumptions and data requirements are desired. If desired, the listing and extra
    prompts in the figure are output. If the response to the last prompt indicates a desire to
    abort the component execution, control branches to step g.

```
ENTER ONE TO WORK WITH CALENDAR TIME COMPONENT; ELSE ZERO.

ENTER ONE FOR CALENDAR TIME COMPONENT DESCRIPTION; ELSE ZERO.

CALENDAR TIME MODEL ASSUMPTIONS

 1. THE QUANTITIES OF THE  AVAILABLE RESOURCES (FAILURE-IDENTI-
    FICATION PERSONNEL, FAILURE-CORRECTION PERSONNEL, AND COM-
    PUTER TIME) ARE CONSTANT OVER TESTING SEGMENTS.

 2. RESOURCE EXPENDITURES FOR THE ITH  RESOURCE ASSOCIATED WITH
    A CHANGE IN MTBNF FROM T1 TO T2 CAN BE APPROXIMATED BY

         THETA(I) * DELTA(TAU) + MU(I) * DELTA(M)

    WHERE

         THETA(I)  - EXECUTION TIME  COEFFICIENT OF RESOURCE EX-
                     PENDITURE FOR THE ITH RESOURCE
```

FIGURE 10-25. MDLMUS CALENDAR TIME COMPONENT DESCRIPTION

```
          DELTA(TAU)- INCREMENT OF EXECUTION TIME ASSOCIATED WITH
                      THE CHANGE IN MTBNF

ENTER ONE TO CONTINUE THE DESCRIPTION LIST.
          MU(I)     - FAILURE COEFFICIENT OF RESOURCE EXPENDITURE
                      FOR THE ITH RESOURCE
          DELTA(M)  - THE INCREMENT OF  FAILURES EXPERIENCED WITH
                      THE CHANGE IN MTBNF

  3. FAILURE IDENTIFICATION PERSONNEL CAN BE FULLY  UTILIZED AND
     COMPUTER UTILIZATION IS CONSTANT.

  4. FAILURE-CORRECTION PERSONNEL  UTILIZATION IS ESTABLISHED BY
     LIMITATION OF  ERROR QUEUE LENGTH  FOR ANY  DEBUGGER. ERROR
     QUEUE LENGTH IS DETERMINED, IN TURN, BY ASSUMING  THE ERROR
     CORRECTION PROCESS IS POISSON  AND THAT THE FAILURE-CORREC-
     TION PERSONNEL ARE RANDOMLY ASSIGNED ERRORS OVER TIME.

ENTER ONE TO CONTINUE THE DESCRIPTION LIST.
MODEL DATA REQUIREMENTS

  1. THE AVAILABLE RESOURCES FOR BOTH FAILURE-IDENTIFICATION AND
     FAILURE-CORRECTION PERSONNEL.

  2. THE NUMBER OF COMPUTER SHIFTS.

  3. THE EXECUTION TIME  COEFFICIENT OF RESOURCE EXPENDITURE FOR
     EACH RESOURCE.

  4. THE FAILURE  COEFFICIENT OF  RESOURCE EXPENDITURE  FOR EACH
     RESOURCE.

  5. THE MAXIMUM ERROR QUEUE LENGTH FOR EACH DEBUGGER.

ENTER ONE TO CONTINUE THE DESCRIPTION LIST.
  6. THE PROBABILITY  THAT THE ERROR  QUEUE  LENGTH IS NO LARGER
     THAN THE MAXIMUM QUEUE LENGTH.

  7. THE COMPUTER UTILIZATION RATIO.

  8. THE DESIRED MTBNF.

IF THE ASSUMPTIONS ARE  GENERALLY SATISFIED AND THE APPROPRIATE
DATA ARE AVAILABLE, ENTER ONE TO CONTINUE THE MODEL;  OTHERWISE
ZERO TO SKIP THE CALENDAR TIME MODEL.
```

FIGURE 10-25. MDLMUS CALENDAR TIME COMPONENT DESCRIPTION (Continued)

f. SMERFS then prompts and inputs the 12 values needed to perform the Calendar Time Component, as shown in Figure 10-26. (Note that after the additional testing time prediction is output, SMERFS allows the user to repeat the execution with only the desired MTBNF changed or additionally with all 12 values reprompted.)

10-17

```
ENTER THE APPROPRIATE DATA AFTER EACH PROMPT
 1 NUMBER OF FAILURE IDENTIFICATION PERSONNEL.
 2 NUMBER OF FAILURE CORRECTION PERSONNEL.
 3 NUMBER OF COMPUTER SHIFTS (EXAMPLE - IF THE WORK WEEK IS 40
   HRS. AND THE COMPUTER IS AVAILABLE 80 HRS. A WEEK, THEN EN-
   TER THE NUMBER 2).
 4 AVERAGE  AMOUNT OF COMPUTER  (WALLCLOCK)  TIME EXPENDED PER
   UNIT OF EXECUTION TIME (CPU).
 5 AVERAGE  AMOUNT OF  IDENTIFICATION  WORK  TIME EXPENDED PER
   UNIT OF EXECUTION TIME.
 6 AVERAGE AMOUNT OF COMPUTER TIME (HRS) EXPENDED PER FAILURE.
 7 AVERAGE  AMOUNT OF  IDENTIFICATION WORK  (HRS) REQUIRED PER
   FAILURE.
 8 AVERAGE  AMOUNT OF CORRECTION WORK (HRS) REQUIRED PER FAIL-
   URE.
 9 MAXIMUM ERROR QUEUE LENGTH FOR A DEBUGGER.
10 ASSOCIATED  PROBABILITY THAT  THE QUEUE  LENGTH  WILL BE NO
   LARGER THAN VALUE JUST INPUT.
11 COMPUTER UTILIZATION FACTOR (0.LT.X.LE.1).
12 ENTER A DESIRED MTBNF  FOR THE PROGRAM (IN HOURS AND LARGER
   THAN THE CURRENT ESTIMATED VALUE OF eeeeeeeeee).

ADDITIONAL HOURS TO MTBNF eeeeeeeeee

ENTER ONE TO USE A DIFFERENT SPECIFIED MTBNF; ELSE ZERO.

ENTER ONE FOR ALL NEW CALENDAR TIME MODEL INPUTS; ELSE ZERO.
```

FIGURE 10-26. MDLMUS COMPONENT PROMPTS AND OUTPUT

g.   SMERFS determines if the execution was successful. If it was, it allows for various analyses of the model fit. This is shown in the prompt of Figure 10-27. Control then automatically transfers to the Analyses of Model Fit sub-module (Chapter 12). Upon completion, control returns to the Execution Time Data Model Menu (Section 10.2, step b).

```
ENTER ONE TO PERFORM AN ANALYSIS OF THE MODEL FIT USING THE PRE-
DICTIONS OF THIS MODEL; ELSE ZERO.
```

FIGURE 10-27. MDLMUS ANALYSES OF MODEL FIT PROMPTS

10.2.5 Musa's Logarithmic Poisson Execution Time Model

If the entered model option number is five, then:

a. SMERFS prompts for a flag indicating whether the model assumptions and data requirements are desired (Figure 10-28). If desired, the listing and extra prompts in the figure are output. If the response to the last prompt indicates a desire to abort the model execution, control returns to Section 10.2, step b. (Refer to Paragraph 10.3.5 for details on the prompted input and generated output.)

```
ENTER ONE FOR MUSA (LOG) MODEL DESCRIPTION; ELSE ZERO.

THE MUSA LOGARITHMIC POISSON EXECUTION TIME MODEL ASSUMPTIONS

  1. THE SOFTWARE IS OPERATED IN A SIMILAR MANNER AS THE ANTICI-
     PATED OPERATIONAL USAGE.

  2. ALL FAULTS ARE EQUALLY LIKELY TO OCCUR  AND ARE INDEPENDENT
     OF EACH OTHER.

  3. THE EXPECTED NUMBER OF FAULTS IS A LOGARITHMIC FUNCTION  OF
     TIME.

  4. THE FAILURE INTENSITY DECREASES EXPONENTIALLY WITH THE  EX-
     PECTED FAILURES EXPERIENCED.

  5. THE  SOFTWARE WILL  EXPERIENCE AN  INFINITE NUMBER OF FAIL-
     URES.

ENTER ONE TO CONTINUE THE DESCRIPTION LIST.
MODEL DATA REQUIREMENTS

  1. THE TIME-BETWEEN-FAILURES AS MEASURED IN COMPUTER CPU TIME.
     THE DATA SHOULD HAVE BEEN ENTERED VIA THE INPUT MODULE.

IF THE ASSUMPTIONS ARE  GENERALLY SATISFIED AND THE APPROPRIATE
DATA ARE AVAILABLE, ENTER ONE TO CONTINUE THE MODEL;  OTHERWISE
ZERO TO RETURN TO THE MENU OF MODELS.
```

FIGURE 10-28. MDLMSA DESCRIPTION PROMPTS AND LIST

b. If the data are not appropriate for this model, then the message shown in Figure 10-29 is issued and control branches to step e.

```
**THE DATA ARE NOT APPROPRIATE FOR THE MODEL.
```

FIGURE 10-29. MDLMSA PROCESSING ERROR MESSAGE

c.   Otherwise (if the solution is obtained), the ML estimates are output (Figure 10-30).

```
THE MAXIMUM LIKELIHOOD ESTIMATES ARE:
 BETA0 PARAMETER           ●●●●●●●●●●●
 BETA1 PARAMETER           ●●●●●●●●●●●
 INIT. INTENSITY FUNCTION  ●●●●●●●●●●●
 CUR.  INTENSITY FUNCTION  ●●●●●●●●●●●
 CUR.  MTBNF               ●●●●●●●●●●●
 PURIFICATION LEVEL        ●●●●●●●●●●●
```

FIGURE 10-30. MDLMSA SUCCESSFUL CONVERGENCE OUTPUT

d.   SMERFS then allows for the processing of future predictions to determine the expected performance of the software (Figure 10-31).

ERROR: If the estimate for the (rounded) number of faults remaining is less than one or the MTBNF is negative, these future predictions are not allowed and the appropriate message shown at the bottom of the figure is issued.

```
THE AVAILABLE FUTURE PREDICTIONS ARE:
 1) THE EXPECTED RELIABILITY FOR A SPECIFIED TIME
 2) THE TOTAL MTBNF FOR THE NEXT K FAILURES
 3) THE TIME AND NUMBER OF FAILURES TO REACH A DESIRED INTENSITY
    FUNCTION
 4) THE NUMBER OF FAILURES EXPECTED IN A SPECIFIED TIME
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.

 ENTER LENGTH OF THE PERIOD, OR ZERO TO END.
 FUTURE RELIABILITY          ●●●●●●●●●●●

 ENTER VALUE OF K, OR ZERO TO END.
 MTBNF EXPECTED              ●●●●●●●●●●●

 ENTER INTENSITY FUNC. (LESS THAN ●●●●●●●●●●●), OR ZERO TO END.
 ADDITIONAL TESTING TIME  ●●●●●●●●●●●
 # OF FAILURES EXPECTED   ●●●●●●●●●●●

 ENTER LENGTH OF THE PERIOD, OR ZERO TO END.
 # OF FAILURES EXPECTED   ●●●●●●●●●●●

**FUTURE PREDICTIONS AND PREDICTED TBFS ARE NOT ALLOWED BECAUSE
 THE BETA0 PARAMETER OF THE MODEL IS LESS THAN OR EQUAL TO ONE.

**FUTURE PREDICTIONS ARE NOT ALLOWED BECAUSE THE ESTIMATE FOR THE
 MTBNF IS LESS THAN ZERO.
```

FIGURE 10-31. MDLMSA FUTURE PREDICTION PROMPTS AND OUTPUT

e. SMERFS determines if the execution was successful and if the indicated BETA parameter is greater than one. If both tests showed true, SMERFS allows for various analyses of the model fit. This is shown in the prompt of Figure 10-32. Control then automatically transfers to the Analyses of Model Fit sub-module (Chapter 12). Upon completion, control returns to the Execution Time Data Model Menu (Section 10.2, step b).

If the parameter BETA0 allows for the TBF prediction, then:

ENTER ONE TO PERFORM AN ANALYSIS OF THE MODEL FIT USING THE PRE-DICTIONS OF THIS MODEL; ELSE ZERO.

End if

FIGURE 10-32. MDLMSA ANALYSES OF MODEL FIT PROMPTS

10.2.6 Non-homogeneous Poisson for Execution Time Data Model

If the entered model option number is six, then:

a.   SMERFS prompts for a flag indicating whether the model assumptions and data requirements
are desired (Figure 10-33). If desired, the listing and extra prompts in the figure are output.
If the response to the last prompt indicates a desire to abort the model execution, control
returns to Section 10.2, step b. (Refer to Paragraph 10.3.6 for details on the prompted input
and generated output.)

```
ENTER ONE FOR NHPP MODEL DESCRIPTION; ELSE ZERO.

THE NON-HOMOGENEOUS POISSON MODEL ASSUMPTIONS

  1. THE SOFTWARE IS OPERATED IN A SIMILAR MANNER AS THE ANTICI-
     PATED OPERATIONAL USAGE.

  2. ALL FAULTS ARE EQUALLY LIKELY TO OCCUR  AND ARE INDEPENDENT
     OF EACH OTHER.

  3. THE  CUMULATIVE NUMBER  OF FAULTS DETECTED AT ANY TIME FOL-
     LOWS A POISSON DISTRIBUTION  WITH MEAN M(T).   THAT  MEAN IS
     SUCH THAT THE EXPECTED  NUMBER OF FAULTS IN  ANY SMALL TIME
     INTERVAL ABOUT T IS PROPORTIONAL  TO THE NUMBER OF UNDETEC-
     TED FAULTS AT TIME T.

  4. THE MEAN IS ASSUMED TO BE A BOUNDED NON-DECREASING FUNCTION
     WITH M(T) APPROACHING IN THE LIMIT, "A" (THE EXPECTED TOTAL
     NUMBER OF FAULTS TO BE, EVENTUALLY, DETECTED IN THE TESTING
     PROCESS), AS THE LENGTH OF TESTING GOES TO INFINITY.

ENTER ONE TO CONTINUE THE DESCRIPTION LIST.
MODEL DATA REQUIREMENTS

  1. THE TIME-BETWEEN-FAILURES AS MEASURED IN WALL CLOCK OR COM-
     PUTER CPU TIME.  THE DATA SHOULD HAVE  BEEN ENTERED VIA THE
     INPUT MODULE.

IF THE ASSUMPTIONS ARE  GENERALLY SATISFIED AND THE APPROPRIATE
DATA ARE AVAILABLE, ENTER ONE TO CONTINUE THE MODEL;  OTHERWISE
ZERO TO RETURN TO THE MENU OF MODELS.
```

FIGURE 10-33. MDLNPT DESCRIPTION PROMPTS AND LIST

b.   If the data are not appropriate for this model or the estimate of the total number of faults is
less than the observed number, then the appropriate message shown in Figure 10-34 is issued
and control branches to step e.

```
**THE DATA ARE NOT APPROPRIATE FOR THE MODEL.

**THE ESTIMATE  FOR THE TOTAL  NUMBER OF FAULTS  TO BE DETECTED IN
  THE PROGRAM BEFORE  ALL FAULTS ARE UNCOVERED  CAME OUT LESS THAN
  THE NUMBER OF FAULTS FOUND TO DATE WITHIN THE MODEL.
```

FIGURE 10-34. MDLNPT PROCESSING ERROR MESSAGES

c.   Otherwise (if the solution is obtained), the ML estimates are output (Figure 10-35).

```
MODEL ESTIMATES ARE:
 PROPORTIONALITY CONSTANT   eeeeeeeeeee
 INIT. INTENSITY FUNCTION   eeeeeeeeeee
 CUR.  INTENSITY FUNCTION   eeeeeeeeeee
 TOTAL NUMBER OF FAULTS     eeeeeeeeeee
 # OF FAULTS REMAINING      eeeeeeeeeee
 PURIFICATION LEVEL         eeeeeeeeeee
```

FIGURE 10-35. MDLNPT SUCCESSFUL CONVERGENCE OUTPUT

d.   SMERFS then allows for the processing of future predictions to determine the expected
     performance of the software (Figure 10-36).

ERROR: If the estimate for the (rounded) number of faults remaining is less than one,
         these future predictions are not allowed and the message shown at the bottom of
         the figure is issued.

```
THE AVAILABLE FUTURE PREDICTIONS ARE:
 1) THE EXPECTED RELIABILITY FOR A SPECIFIED TIME
 2) THE TIME TO  REACH A SPECIFIED  RELIABILITY FOR A SPECIFIED
    OPERATIONAL TIME
 3) THE TIME TO REACH A DESIRED INTENSITY FUNCTION
 4) THE NUMBER OF FAILURES EXPECTED IN A SPECIFIED TIME
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.

ENTER LENGTH OF THE PERIOD, OR ZERO TO END.
FUTURE RELIABILITY          eeeeeeeeeee

ENTER DESIRED RELIABILITY, OR ZERO TO END.
ENTER SPECIFIED OPERATIONAL TIME.
ADDITIONAL TESTING TIME  eeeeeeeeeee
```

FIGURE 10-36. MDLNPT FUTURE PREDICTION PROMPTS AND OUTPUT

```
    ENTER INTENSITY FUNC. (LESS THAN eeeeeeeeee), OR ZERO TO END.
    ADDITIONAL TESTING TIME   eeeeeeeeeee

    ENTER LENGTH OF THE PERIOD, OR ZERO TO END.
    # OF FAILURES EXPECTED     eeeeeeeeeee

**FUTURE PREDICTIONS ARE NOT ALLOWED  BECAUSE THE ESTIMATE FOR THE
  (ROUNDED) NUMBER OF FAULTS REMAINING IS LESS THAN ONE.
```

FIGURE 10-36. MDLNPT FUTURE PREDICTION PROMPTS AND OUTPUT (Continued)

e.   SMERFS determines if the execution was successful. If it was, it allows for various analyses of the model fit. This is shown in the prompt of Figure 10-37. Control then automatically transfers to the Analyses of Model Fit sub-module (Chapter 12). Upon completion, control returns to the Execution Time Data Model Menu (Section 10.2, step b).

```
    ENTER ONE TO PERFORM AN ANALYSIS OF THE MODEL FIT USING THE PRE-
    DICTIONS OF THIS MODEL; ELSE ZERO.
```

FIGURE 10-37. MDLNPT ANALYSES OF MODEL FIT PROMPTS

10.3 MODEL OUTPUTS AND CONSIDERATIONS

The reader is directed to the references for a detailed description of the model parameters and outputs covered in this chapter. Reference 2 is especially applicable unless indicated otherwise in this section. This section briefly discusses the meaning of required inputs and displayed outputs for each model. Considerations for requested inputs are also discussed. One of the biggest changes from SMERFS version 3 to 4 (thus incorporated in version 5) is that most of the models no longer require inputted starting values for the optimization procedures for model parameter estimation. The models using the Dekker-Brent optimization procedure have built-in calculations for such values and, as a result, no user input is required. The only model not employing this technique in this section is the Littlewood and Verrall Bayesian Reliability Growth Model. This model employs the Trust Region methodology. This technique will still, however, determine starting values or let the user override them by inputting different values.

The time units for all outputs of a selected model are expressed in those units selected by the user for the data set. This is true for all models except the Calendar Time Component of Musa's Basic Execution Time model. For that component, the output is expressed in the number of hours required to achieve the desired reliability level, regardless of the units of the failure data.

10.3.1 Geometric Model

Besides the estimates of the parameters defining the model, the output includes estimates for:

a. Initial intensity function
b. Current intensity function
c. MTBNF
d. Current purification level

The intensity function is how fast the expected MTBNF function is changing with respect to time. The initial is at time $t=0$, while the current is at the present time. The purification level is the relative "fault-freeness" of the code. The closer the value is to one, the "purer" is the code. When all faults have been found and eliminated, the value is exactly one.

For prediction purposes, the model provides:

a. Total MTBNF for the next K failures
b. Time and number of failures to reach a desired intensity function
c. Number of failures expected in a specified time

The total MTBNF for the next K failures is the expected length of time (expressed in the user-selected units) until exactly K failures will have occurred. The time and number of failures to reach a desired intensity function will provide an estimate of how long it will take and how many failures are to be expected until a desired intensity function (failures / unit of time) is achieved. The last prediction statistic is self-explanatory. All of these quantities can be used for tradeoff analyses to determine optimal release time of the software or to determine when a given operational program is a prime candidate for a rewrite.

10.3.2 Jelinski/Moranda De-Eutrophication Model

Besides the same outputs provided by the Geometric model (Paragraph 10.3.1), the Jelinski/ Moranda model also gives an estimate of the total number of faults and the number of faults remaining in the code. The number remaining is simply obtained from the estimate of the total number of faults by subtracting the number found to date.

In addition to the same prediction estimates as provided by the Geometric model, this model also allows the user to obtain an estimate of the expected reliability (i.e., probability of the software not failing) over a specified time period that the user enters. Again, tradeoff analyses can be used to determine optimal release or rewrite time.

10.3.3 Littlewood and Verrall's Bayesian Reliability Growth Model

If the user decides to override the initial estimates for BETA(0) and BETA(1), (e.g., explore for a global maximum), the values that are input should be in the range 1.0E-07 and 1.0E+07. Values for BETA(0), in addition, should be tried between 0 and 1 for initial exploration. The "FUNCTION" that is mentioned in the output (see Figure 10-17) is either the likelihood function in the case of the maximum likelihood estimates or the residual sums-of-squares for the least squares estimates (Reference 2). This quantity is especially useful in determining when a global solution has been obtained.

The model output includes estimates for:

a. Initial intensity function
b. Current intensity function
c. Current MTBNF

The intensity function is the derivative of the MTBNF function with respect to time. The initial is this derivation at time $t=0$, and the current is the derivation at the present time. It provides the user an idea of the rate at which failures are occurring at a given point in time.

For prediction purposes, the model provides:

a. Total MTBNF for the next K failures
b. Time and number of failures to reach a desired intensity function
c. Number of failures expected in a specified time

The total MTBNF for the next K failures is the expected length of time (expressed in the user-selected units) until exactly K failures will have occurred. The time and number of failures to reach a desired intensity function (which is only available for the linear option) will provide an estimate of how long it will take and how many failures are to be expected until a desired intensity function (failures / unit of time) is achieved. The last prediction statistic is self-explanatory. All of these quantities can be used for tradeoff analyses to determine optimal release time of the software or to determine when a given operational program is a prime candidate for a rewrite.

10.3.4 Musa's Execution Time Model

If convergence is achieved, the SMERFS program estimates, in addition to the model parameters, include:

    a. Initial intensity function
    b. Current intensity function
    c. Initial MTBNF
    d. Current MTBNF
    d. Total number of faults
    e. Number of faults remaining
    f. Purification level

The initial intensity function is the rate at which failures are occurring at time $t = 0$, and the current is the rate at the present time. The purification level is the relative "fault-freeness" of the code. The closer the value is to one, the "purer" is the code. When all faults have been found and eliminated, the value is exactly one.

Besides all of the prediction statistics that the Geometric model (Paragraph 10.3.1) provides, this model also allows the user to estimate the number of failures required to reach a desired MTBNF. All of these prediction statistics can be used for tradeoff analyses to determine optimal release time of the software or to determine when a given operational program is a prime candidate for a rewrite.

For the input to the Calendar Time Component, most of the prompts are self-explanatory. The failure identification personnel are the testers and the failure correction personnel are the program maintainers. The maximum queue length for a debugger is the maximum number of errors that are assigned to any one programmer to correct. Finally, the computer utilization factor is that fraction of capacity at which the computer operates. The additional hours that are needed to meet the specified MTBNF is expressed in WC hours rather than CPU time shown in the first part of the model output.

For a more detailed explanation of all these quantities, see Reference 5.

10.3.5 Musa's Logarithmic Poisson Execution Time Model

Besides the model parameters, the output includes all of the outputs of the Musa Basic Execution Time model (Paragraph 10.3.4) except for the initial MTBNF and the total number of faults (therefore the total remaining), since this model assumes that an infinite number of faults are present in the code.

For prediction statistics, all have been considered already in the previous description for the Geometric model (Paragraph 10.3.1) and the Jelinski/Moranda model (Paragraph 10.3.2).

10.3.6 Non-homogenous Poisson Model for Execution Time Data

Besides the estimates of the model parameters, the output includes estimates for:

a. Initial intensity function
b. Current intensity function
c. Total number of faults
d. Number of faults remaining
e. Purification level

See the description of the Musa Basic Execution Time model (Paragraph 10.3.4) for explanations of these quantities.

For prediction statistics, the outputs are:

a. Expected reliability for a specified time
b. Time to reach a specified reliability for a specified operational time
c. Time to reach a desired intensity function
d. Number of failures expected in a specified time

For the expected reliability (i.e., probability of the software not failing) for a specified time, the user inputs a given length in the user-specified units of time and the program will provide an estimate of that reliability. The program can provide the user an estimate of the required time needed to achieve a specified reliability for a specified operational time. For example, if .95 was entered for the desired reliability with a specified operational time (measured in CPU time) of 10 hours, the resulting output would be the amount of testing time (again measured in CPU time) that would have to be expended to achieve the stated goal. If the user were to expend this amount, the probability would be .95 that the software would operate 10 CPU hours without failure. The remaining prediction statistics have been considered previously (Paragraph 10.3.1).

CHAPTER 11

SOFTWARE RELIABILITY INTERVAL DATA MODULE

11.1 INTRODUCTION

This module explains the execution of five software reliability models that obtain reliability estimates and predications for interval data. Entry of a Main module option number of eight automatically directs the program to this module if interval data are resident (i.e., the data type was entered as a four). Chapter 10 explains the execution of the six software reliability models that obtain reliability estimates and predictions for TBF data (i.e., the data type was entered as a one, two, or three).

11.2 EXECUTION FLOW

This section explains the prompts and inputs for the software reliability portion of SMERFS pertaining to interval data. The placement of and the print in the figures conform to the strategy introduced in Sections 1.5 and 1.6.

a. Software Reliability Model Selection

SMERFS first prompts the user to enter the desired software reliability model (Figure 11-1). If an invalid option number is entered, the same list and second prompt are output.

```
ENTER COUNT MODEL OPTION, OR ZERO FOR A LIST.
THE AVAILABLE FAULT COUNT MODELS ARE:
 1 THE BROOKS AND MOTLEY MODEL
 2 THE GENERALIZED POISSON MODEL
 3 THE NON-HOMOGENEOUS POISSON MODEL
 4 THE SCHNEIDEWIND MODEL
 5 THE S-SHAPED RELIABILITY GROWTH MODEL
 6 RETURN TO THE MAIN PROGRAM
ENTER MODEL OPTION.
```

FIGURE 11-1. INTERVAL DATA MODEL MENU

b.   Transfer to the Indicated Model

If the entered model option number is six, control returns to the Main Module Menu (Chapter 2, step h). Otherwise (if a valid model number is entered), the program transfers control to the indicated model, where:

1. The Brooks and Motley model is contained in Paragraph 11.2.1.
2. The Generalized Poisson model is contained in Paragraph 11.2.2.
3. The Non-homogeneous Poisson model is contained in Paragraph 11.2.3.
4. The Schneidewind model is contained in Paragraph 11.2.4.
5. The S-Shaped Reliability Growth model is contained in Paragraph 11.2.5.

11.2.1. Brooks and Motley's Discrete Software Reliability Model

If the entered model option number is one, then:

a.   SMERFS prompts for a flag indicating whether the model assumptions and data requirements are desired (Figure 11-2). If desired, the listing and extra prompts in the figure are output. If the response to the last prompt indicates a desire to abort the model execution, control returns to Section 11.2, step a. (Refer to Paragraph 11.3.1 for details on the prompted input and generated output.)

```
ENTER ONE FOR BROOKS AND MOTLEY MODEL DESCRIPTION; ELSE ZERO.

THE BROOKS AND MOTLEY DISCRETE SR MODEL ASSUMPTIONS

   1. THE SOFTWARE IS OPERATED IN A SIMILAR MANNER AS THE ANTICI-
      PATED OPERATIONAL USAGE.

   2. ALL FAULTS ARE EQUALLY LIKELY TO OCCUR  AND ARE INDEPENDENT
      OF EACH OTHER.

   3. EACH FAULT IS OF THE SAME ORDER OF "IMPACT" AS ANY OTHER.

   4. THE NUMBER OF SOFTWARE FAULTS DETECTED ON EACH TESTING OC-
      CASION IS PROPORTIONAL TO THE NUMBER OF  FAULTS AT RISK FOR
      DETECTION.  THIS, IN TURN, IS PROPORTIONAL TO THE NUMBER OF
      FAULTS REMAINING.

   5. THE PROPORTIONALITY FACTOR OR PROBABILITY (DENOTED AS Q FOR
      THE BINOMIAL MODEL AND PHI FOR THE POISSON MODEL) OF DETEC-
      TING ANY FAULT DURING A SPECIFIED  UNIT INTERVAL OF TESTING
      IS CONSTANT OVER ALL OCCASIONS AND INDEPENDENT OF THE FAULT
      DETECTIONS.

ENTER ONE TO CONTINUE THE DESCRIPTION LIST.
   6. THE FAULTS REINTRODUCED  IN THE CORRECTION PROCESS ARE PRO-
      PORTIONAL TO THE NUMBER OF FAULTS DETECTED.

MODEL DATA REQUIREMENTS

   1. THE NUMBER OF FAULTS  DETECTED IN EACH INTERVAL OF TESTING.

   2. THE LENGTHS OF THE VARIOUS TESTING INTERVALS.

   "1 & 2 SHOULD HAVE BEEN ENTERED VIA THE DATA INPUT MODULE."

IF THE ASSUMPTIONS ARE  GENERALLY SATISFIED AND THE APPROPRIATE
DATA ARE AVAILABLE, ENTER ONE TO CONTINUE THE MODEL;  OTHERWISE
ZERO TO RETURN TO THE MENU OF MODELS.
```

FIGURE 11-2. MDLBAM DESCRIPTION PROMPTS AND LIST

b.	SMERFS then permits an extended description of the Binomial and Poisson models, by issuing the prompt shown in Figure 11-3. If the response entered indicates that the additional information is desired, the listing in the figure is output.

```
ENTER ONE FOR DETAILS ON THE BINOMIAL AND POISSON METHODS;  ELSE
ZERO.

IN THE BINOMIAL MODEL,  IT IS ASSUMED THAT THE NUMBER OF FAULTS
DETECTED IN THE  I-TH  INTERVAL OF TESTING  FOLLOWS  A BINOMIAL
DISTRIBUTION WITH PARAMETERS N(I) AND Q(I), WHERE:

    Q(I) = 1 - (1 - Q) ** T(I);
      T(I) IS THE LENGTH OF THE I-TH TESTING PERIOD, AND
      Q IS THE FAULTS DETECTION PROBABILITY,

AND

    N(I) = N * W(I) - ALPHA * NCUM(I-1);
      N IS THE TOTAL NUMBER OF FAULTS IN THE PROGRAM,
      W(I) IS THE  FRACTION  OF THE PROGRAM  BEING TESTED ON THE
      I-TH TESTING OCCASION,
      NCUM(I-1) IS THE CUMULATIVE NUMBER OF FAULTS FOUND IN THIS
      SECTION OF THE CODE THROUGH THE (I-1)ST TESTING PERIOD AND
      ALPHA IS THE PROBABILITY OF CORRECTING FAULTS  WITHOUT RE-
      INSERTING NEW ONES.

ENTER ONE TO CONTINUE THE DESCRIPTION LIST.
IN THE POISSON  MODEL,  IT IS ASSUMED THAT THE NUMBER OF FAULTS
DETECTED IN THE  I-TH  INTERVAL OF TESTING  FOLLOWS  A  POISSON
DISTRIBUTION WITH PARAMETER
LAMDA(I) = N(I) * PHI(I) WHERE:

    PHI(I) = 1 - (1 - PHI) ** T(I);
      T(I) IS THE LENGTH OF THE I-TH TESTING PERIOD, AND
      PHI IS THE FAULT DETECTION PROBABILITY

AND

    N(I) = N * W(I) - ALPHA * NCUM(I-1);
      N IS THE TOTAL NUMBER OF FAULTS IN THE PROGRAM,
      W(I) IS THE  FRACTION OF THE  PROGRAM BEING TESTED  ON THE
      I-TH TESTING OCCASION,
      NCUM(I-1) IS THE CUMULATIVE NUMBER OF FAULTS FOUND IN THIS
      SECTION OF THE CODE THROUGH  THE (I-1)ST TESTING PERIOD, &
      ALPHA IS THE PROBABILITY OF CORRECTING FAULTS  WITHOUT RE-
      INSERTING NEW ONES.
```

FIGURE 11-3. MDLBAM EXTENDED DESCRIPTION PROMPTS AND LIST

c.	SMERFS prompts for a flag indicating whether the program testing plan involved the entire program or only a fraction of the program, as shown in the first prompt of Figure 11-4. If the testing included the entire program, SMERFS constructs both the fractional portion vector and the vector containing the number of faults detected (in that fractional portion) in

the previous testing periods. Otherwise, SMERFS prompts the user to enter both values for each testing period, as shown in the second prompt of the figure.

```
ENTER ONE TO INPUT  THE FRACTION OF THE PROGRAM  BEING TESTED AT
EACH TESTING PERIOD, OR ZERO TO SET THE FRACTIONS ALL EQUAL TO 1
(I.E., THE ENTIRE PROGRAM WAS UNDER TEST IN EACH OCCASION).

If a positive response was input, then a series of:

ENTER FRACTION OF CODE BEING TESTED IN PERIOD iii  AND THE NUM-
BER OF FAULTS DETECTED  IN THE FRACTIONAL PART  IN THE PREVIOUS
ii TEST PERIODS.

End if
```

FIGURE 11-4. MDLBAM FRACTION OF CODE UNDER TEST PROMPTS

d. SMERFS prompts the user to enter the desired model (Binomial or Poisson) or a value to terminate this model execution (Figure 11-5). If the termination value is entered, control branches to step h. If a desired model is selected, then the initial estimates for both the probability of detecting faults and the total number of faults are internally established. Those values are then output (Figure 11-5) and SMERFS allows the user to override the values to ensure that the global maximum has been reached. The program prompts for the probability that a fault will not be inserted while one is being corrected. Lastly, the program prompts for the maximum number of convergence iterations.

```
ENTER ONE FOR THE BINOMIAL MODEL,  TWO FOR THE POISSON MODEL, OR
THREE TO TERMINATE MODEL EXECUTION.

THE INITIAL ESTIMATES TO BE USED IN THE ESTIMATION PROCESS ARE:
 PROB. OF DETECTING FAULTS eeeeeeeeeee
 TOTAL NUMBER OF FAULTS     eeeeeeeeeee

ENTER ONE TO USE DIFFERENT INITIAL ESTIMATES, OR ZERO TO USE THE
INITIAL ESTIMATES.

If user override was selected, then:

 ENTER INITIAL ESTIMATE FOR THE PROBABILITY OF DETECTING FAULTS
 (BETWEEN 0.10000E-06 AND 0.99999E-00).

 ENTER INITIAL ESTIMATE FOR THE TOTAL NUMBER OF FAULTS
 (BETWEEN eeeeeeeeeee AND 0.10000E+08).

End if
```

FIGURE 11-5. MDLBAM INPUT PROMPTS

```
ENTER THE DESIRED ALPHA (PROBABILITY OF CORRECTING FAULTS IN THE
PROGRAM WITHOUT INSERTING NEW ONES).

ENTER MAXIMUM NUMBER OF ITERATIONS.
```

FIGURE 11-5. MDLBAM INPUT PROMPTS (Continued)

e.   If the maximum number of iterations is reached before a solution is found, the Trust Region could not be adjusted properly using the values for the initial estimates, or the estimate of the total number of faults is less than the observed number, then the appropriate message shown in Figure 11-6 (including the BINOMIAL or POISSON indicator) is issued and control returns to step d.

```
**THE MAXIMUM NUMBER OF ITERATIONS WAS REACHED   WITH THE FOLLOWING
FINAL aaaaaaaa MODEL ESTIMATES:
  PROB. OF DETECTING FAULTS eeeeeeeeeee
  TOTAL NUMBER OF FAULTS    eeeeeeeeeee
  # OF FAULTS REMAINING     eeeeeeeeeee

**THE TRUST REGION COULD NOT BE ADJUSTED PROPERLY FOR THE aaaaaaaa
MODEL.

**THE ESTIMATE FOR THE TOTAL  NUMBER OF FAULTS  TO BE DETECTED IN
THE PROGRAM BEFORE  ALL FAULTS ARE UNCOVERED  CAME OUT LESS THAN
THE NUMBER OF FAULTS FOUND TO DATE WITHIN THE aaaaaaaa MODEL.
```

FIGURE 11-6. MDLBAM PROCESSING ERROR MESSAGES

f.   Otherwise (if the solution is obtained), the BINOMIAL or POISSON estimates are output, including the number of iterations performed to obtain those estimates (Figure 11-7).

```
THE aaaaaaaa MODEL ESTIMATES, AFTER iii ITERATIONS ARE:
  PROB. OF DETECTING FAULTS eeeeeeeeeee
  TOTAL NUMBER OF FAULTS    eeeeeeeeeee
  # OF FAULTS REMAINING     eeeeeeeeeee
```

FIGURE 11-7. MDLBAM SUCCESSFUL CONVERGENCE OUTPUT

g.   SMERFS then allows for the processing of future predictions to determine the expected performance of the software (Figure 11-8). Upon completion control returns to step d.

NOTE 1: The SMERFS program attempts to minimize the number of prompted values by cycling only on the final value (i.e., the values entered for the fraction of the program being tested and the number of faults discovered in that section are prompted only once; the length is prompted until the zero is entered). If changing of one of the "fixed" values is desired, a zero should be entered to end the current predictions, and then the same prediction option re-selected. All the values will then be prompted.

NOTE 2: Certain predictions can result in infinite looping; the SMERFS program guards against this condition through an internal program maximum. If that maximum is reached, an error message is issued. Additionally, the user is allowed to change that maximum if it is felt that the maximum is too high or too low (refer to the second predictions of the figure).

ERROR: If the estimate for the (rounded) number of faults remaining is less than one, these future predictions are not allowed and the message shown at the bottom of the figure is issued.

```
THE AVAILABLE FUTURE PREDICTIONS ARE:
 1) THE NUMBER OF FAULTS EXPECTED IN THE NEXT TESTING PERIOD
 2) THE NUMBER OF PERIODS NEEDED TO DISCOVER THE NEXT M FAULTS
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.

ENTER FRACTION OF THE PROGRAM TO BE TESTED (FOR ENTIRE PROGRAM,
ENTER ONE).
HOW MANY FAULTS  HAVE BEEN FOUND TO DATE  IN THE SECTION OF THE
CODE TO BE TESTED?
ENTER PROJECTED LENGTH OF THE PERIOD, OR ZERO TO END.
# OF FAULTS EXPECTED        eeeeeeeeeee

ENTER PROJECTED LENGTH OF THE PERIODS.
ENTER FRACTION OF THE PROGRAM TO BE TESTED (FOR ENTIRE PROGRAM,
ENTER ONE).
HOW MANY FAULTS  HAVE BEEN FOUND TO DATE  IN THE SECTION OF THE
CODE TO BE TESTED?
ENTER VALUE OF M (BETWEEN ONE AND eeeeeeeeeee), OR ZERO TO END.
# OF PERIODS EXPECTED       eeeeeeeeeee

If the maximum iterations (1000) is reached, then:

**# OF PERIODS EXCEEDS        eeeeeeeeeee (PROGRAM MAXIMUM)
 ENTER ONE TO CHANGE THE PROGRAM MAXIMUM; ELSE ZERO.
 ENTER THE NEW VALUE FOR THE PROGRAM MAXIMUM.

End if

**FUTURE PREDICTIONS ARE NOT ALLOWED  BECAUSE THE ESTIMATE FOR THE
 (ROUNDED) NUMBER OF FAULTS REMAINING IS LESS THAN ONE.
```

FIGURE 11-8. MDLBAM FUTURE PREDICTION PROMPTS AND OUTPUT

h. The user has responded to the prompt in step d with a value equated to termination. Before the return is performed, SMERFS determines if the last execution for either of the methods of estimation was successful; if either was, it allows for various analyses of the model fit. This is shown in the first prompt of Figure 11-9. Additionally, if both the Binomial and Poisson methods were successful, the second prompt is issued, allowing the user to select the set of estimates to be used in the analyses. Control then automatically transfers to the Analyses of Model Fit sub-module (Chapter 12). Upon completion, control returns to the Interval Data Model Menu (Section 11.2, step a).

```
ENTER ONE TO PERFORM AN ANALYSIS OF THE MODEL FIT USING THE PRE-
DICTIONS OF THIS MODEL; ELSE ZERO.

If Binomial and Poisson were successful, then:

ENTER ONE FOR PREDICTIONS BASED ON BINOMIAL, OR TWO FOR POISSON.

End if
```

FIGURE 11-9. MDLBAM ANALYSES OF MODEL FIT PROMPTS

11.2.2. Generalized Poisson Model

If the entered model option number is two, then:

a. SMERFS prompts for a flag indicating whether the model assumptions and data requirements are desired (Figure 11-10). If desired, the listing and extra prompts in the figure are output. If the response to the last prompt indicates a desire to abort the model execution, control returns to Section 11.2, step a. (Refer to Paragraph 11.3.2 for details on the prompted input and generated output.)

```
ENTER ONE FOR GENERALIZED POISSON MODEL DESCRIPTION; ELSE ZERO.

THE GENERALIZED POISSON MODEL ASSUMPTIONS

  1. THE SOFTWARE IS OPERATED IN A SIMILAR MANNER AS THE ANTICI-
     PATED OPERATIONAL USAGE.

  2. ALL FAULTS ARE EQUALLY LIKELY TO OCCUR  AND ARE INDEPENDENT
     OF EACH OTHER.

  3. EACH FAULT IS OF THE SAME ORDER OF "IMPACT" AS ANY OTHER.

  4. THE EXPECTED NUMBER OF FAULTS  OCCURRING IN ANY TIME INTER-
     VAL IS  PROPORTIONAL TO THE  FAULT CONTENT  AT THE  TIME OF
     TESTING, AND TO SOME  FUNCTION OF THE  AMOUNT OF TIME SPENT
     IN TESTING.

  5. FAULTS ARE CORRECTED  AT THE ENDS OF THE TESTING INTERVALS,
     WITHOUT INTRODUCING NEW ONES.

ENTER ONE TO CONTINUE THE DESCRIPTION LIST.
MODEL DATA REQUIREMENTS

  1. THE NUMBER OF FAULTS  DETECTED IN EACH INTERVAL OF TESTING.

  2. THE LENGTHS OF THE VARIOUS TESTING INTERVALS.

     "1 & 2 SHOULD HAVE BEEN ENTERED VIA THE DATA INPUT MODULE."

  3. THE NUMBER OF FAULTS  CORRECTED AT THE  END OF EACH TESTING
     PERIOD.

IF THE ASSUMPTIONS ARE  GENERALLY SATISFIED AND THE APPROPRIATE
DATA ARE AVAILABLE, ENTER ONE TO CONTINUE THE MODEL;  OTHERWISE
ZERO TO RETURN TO THE MENU OF MODELS.
```

FIGURE 11-10. MDLGPO DESCRIPTION PROMPTS AND LIST

b. SMERFS prompts for a flag indicating whether fault corrections were performed in the same interval in which they were detected (Figure 11-11). If all fault detections and corrections occurred in the same intervals, the program constructs the fault correction vector; otherwise,

SMERFS prompts the user to enter the number corrected at the end of each testing period, as shown in the second prompt of the figure.

```
 ENTER ONE IF ANY FAULTS DETECTED  IN A GIVEN TESTING PERIOD WERE
 CORRECTED IN A LATER PERIOD; ELSE ZERO.

If a positive response was input, then a series of:

 ENTER NUMBER CORRECTED AT THE END OF PERIOD iii.

End if
```

FIGURE 11-11. MDLGPO CORRECTION VECTOR CREATION PROMPTS

c. SMERFS then prompts the user to enter the desired method of estimation (ML or LS) or a value to terminate this model execution (Figure 11-12). If the termination value is entered, control branches to step g. If a method of estimation is selected, then SMERFS prompts for the desired Weighting function number. If an invalid option number is entered, the same list and third prompt are output. The output of the third option only occurs during a ML estimation execution (in which the testing intervals are of unequal lengths). Entry of a three during a LS estimation or a ML estimation in which the testing intervals are all equal is treated as an invalid response.

The remaining program prompts (and required user inputs) are contingent upon the method of estimation and the Weighting function number. The following rules apply:

1. For the Schick-Wolverton method, no additional inputs are required.

2. For the ALPHA input method, the value for ALPHA is prompted (Figure 11-12).

3. For the ML ALPHA estimated method, the initial estimates for both the total number of faults and ALPHA are internally established. Those values are then output and SMERFS allows the user to override the values to ensure that the global maximum has been reached (Figure 11-12). Then the program prompts for the maximum number of convergence iterations.

```
   ENTER ONE FOR  MAXIMUM LIKELIHOOD METHOD,  TWO FOR LEAST SQUARES
   METHOD, OR THREE TO TERMINATE MODEL EXECUTION.

   ENTER WEIGHTING FUNCTION NUMBER, OR ZERO FOR A LIST.
   THE AVAILABLE WEIGHTING FUNCTIONS ARE:
    1 X(I) ** 2 / 2 (SCHICK-WOLVERTON MODEL)
    2 X(I) ** ALPHA (WHERE ALPHA IS INPUT)

If the ML method was selected, then:

If the testing lengths are variable, then:

    3 X(I) ** ALPHA (WHERE ALPHA IS ESTIMATED)

Else, if the testing lengths are all equal, then:

    * ALPHA CANNOT BE ESTIMATED IF THE INTERVAL LENGTHS ARE FIXED.

End if

End if

   ENTER WEIGHTING FUNCTION NUMBER.

If the ALPHA input method was selected, then:

   ENTER DESIRED ALPHA.

Else, if the ALPHA estimated method was selected, then:

   THE INITIAL ESTIMATES TO BE USED IN THE ESTIMATION PROCESS ARE:
   TOTAL NUMBER OF FAULTS    eeeeeeeeeee
   ALPHA                     eeeeeeeeeee

   ENTER ONE TO USE DIFFERENT INITIAL ESTIMATES, OR ZERO TO USE THE
   INITIAL ESTIMATES.

If user override was selected, then:

   ENTER INITIAL ESTIMATE FOR THE TOTAL NUMBER OF FAULTS
   (BETWEEN eeeeeeeeeee AND 0.10000E+08).

   ENTER INITIAL ESTIMATE FOR ALPHA
   (BETWEEN 0.00000E+00 AND 0.10000E+08).

End if

   ENTER MAXIMUM NUMBER OF ITERATIONS.

End if
```

FIGURE 11-12. MDLGPO INPUT PROMPTS

d.   If the maximum number of iterations is reached before a solution is found, the Trust Region could not be adjusted properly using the initial estimates for ALPHA and the total number of faults, the data are not appropriate for this model, or the estimate of the total number of

faults is less than the observed number, then the appropriate message shown in Figure 11-13 (including the ML or LS indicator and the Weighting function number) is issued and control returns to step c.

```
**THE MAXIMUM NUMBER OF ITERATIONS WAS REACHED  WITH THE FOLLOWING
  FINAL ML MODEL ESTIMATES, USING THE WEIGHTING FUNCTION TYPE 3:
   PROPORTIONALITY CONSTANT  eeeeeeeeeee
   TOTAL NUMBER OF FAULTS     eeeeeeeeeee
   # OF FAULTS REMAINING      eeeeeeeeeee
   AND ALPHA                  eeeeeeeeeee

**THE TRUST REGION COULD NOT BE ADJUSTED PROPERLY FOR THE ML MODEL
  USING THE WEIGHTING FUNCTION TYPE 3.

**THE DATA ARE NOT APPROPRIATE  FOR THE aa MODEL, USING THE WEIGH-
  TING FUNCTION TYPE i.

**THE ESTIMATE  FOR THE TOTAL  NUMBER OF FAULTS  TO BE DETECTED IN
  THE PROGRAM BEFORE  ALL FAULTS ARE UNCOVERED  CAME OUT LESS THAN
  THE NUMBER OF FAULTS FOUND  TO DATE WITHIN  THE aa MODEL,  USING
  THE WEIGHTING FUNCTION TYPE i.
```

FIGURE 11-13. MDLGPO PROCESSING ERROR MESSAGES

e.   Otherwise (if the solution is obtained), the ML or LS estimates are output, including the Weighting function number (Figure 11-14). Within that figure, the upper report (containing the 95-percent confidence intervals) corresponds to the ML estimates with a Weighting function number of one or two. The middle report corresponds to the LS estimates with a Weighting function number of one or two. The lower report (containing the additional values for ALPHA and the number of iterations performed to obtain those estimates) corresponds to the ML estimates with a Weighting function number of three.

```
If the ML method (other than ALPHA estimated) was selected, then:

  ML MODEL ESTIMATES, USING THE WEIGHTING FUNCTION TYPE i ARE:
  (THE APPROXIMATE 95% CONFIDENCE INTERVALS APPEAR IN PARENTHESES)
   PROPORTIONALITY CONSTANT  eeeeeeeeeee ( eeeeeeeeee, eeeeeeeeee)
   TOTAL NUMBER OF FAULTS     eeeeeeeeeee ( eeeeeeeeee, eeeeeeeeee)
   # OF FAULTS REMAINING      eeeeeeeeeee ( eeeeeeeeee, eeeeeeeeee)

Else, if the LS method was selected, then:

  LS MODEL ESTIMATES, USING THE WEIGHTING FUNCTION TYPE i ARE:
   PROPORTIONALITY CONSTANT  eeeeeeeeeee
   TOTAL NUMBER OF FAULTS     eeeeeeeeeee
   # OF FAULTS REMAINING      eeeeeeeeeee
```

FIGURE 11-14. MDLGPO SUCCESSFUL CONVERGENCE OUTPUT

```
Else, if the ML method (with ALPHA estimated) was selected, then:

  ML MODEL ESTIMATES,  USING THE WEIGHTING FUNCTION TYPE 3,  AFTER
  iii ITERATIONS ARE:
   PROPORTIONALITY CONSTANT  ●●●●●●●●●●●
   TOTAL NUMBER OF FAULTS    ●●●●●●●●●●●
   # OF FAULTS REMAINING     ●●●●●●●●●●●
   AND ALPHA                 ●●●●●●●●●●●

End if
```

FIGURE 11-14. MDLGPO SUCCESSFUL CONVERGENCE OUTPUT (Continued)

f.   SMERFS then allows for the processing of future predictions to determine the expected performance of the software (Figure 11-15). Upon completion, control returns to step c.

NOTE 1:   The SMERFS program attempts to minimize the number of prompted values by cycling only on the final value (i.e., the value entered for the projected length of the period is prompted only once; the value for the number of faults to discover is prompted until the zero is entered). If changing of the "fixed" value is desired, a zero should be entered to end the current predictions, and then the same prediction option re-selected. Both values will then be prompted.

NOTE 2:   Certain predictions can result in infinite looping; the SMERFS program guards against this condition through an internal program maximum. If that maximum is reached, an error message is issued. Additionally, the user is allowed to change that maximum if it is felt that the maximum is too high or too low (refer to the second predictions of the figure).

ERROR: If the estimate for the (rounded) number of faults remaining is less than one, these future predictions are not allowed and the message shown at the bottom of the figure is issued.

```
THE AVAILABLE FUTURE PREDICTIONS ARE:
 1) THE NUMBER OF FAULTS EXPECTED IN THE NEXT TESTING PERIOD
 2) THE NUMBER OF PERIODS NEEDED TO DISCOVER THE NEXT M FAULTS
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.

ENTER PROJECTED LENGTH OF THE PERIOD, OR ZERO TO END.
# OF FAULTS EXPECTED       ●●●●●●●●●●● ( ●●●●●●●●●●; ●●●●●●●●●●)

ENTER PROJECTED LENGTH OF THE PERIODS.
ENTER VALUE OF M (BETWEEN ONE AND ●●●●●●●●●●●), OR ZERO TO END.
# OF PERIODS EXPECTED      ●●●●●●●●●●●
```

FIGURE 11-15. MDLGPO FUTURE PREDICTION PROMPTS AND OUTPUT

```
If the maximum iterations (1000) is reached, then:

**# OF PERIODS EXCEEDS        eeeeeeeeee (PROGRAM MAXIMUM)
   ENTER ONE TO CHANGE THE PROGRAM MAXIMUM; ELSE ZERO.
   ENTER THE NEW VALUE FOR THE PROGRAM MAXIMUM.

End if

**FUTURE PREDICTIONS ARE NOT ALLOWED  BECAUSE THE ESTIMATE FOR THE
  (ROUNDED) NUMBER OF FAULTS REMAINING IS LESS THAN ONE.
```

FIGURE 11-15. MDLGPO FUTURE PREDICTION PROMPTS AND OUTPUT (Continued)

g.   The user has responded to the prompt in step c with a value equated to termination. Before the return is performed, SMERFS determines if the last execution for either of the methods of estimation was successful; if either was, it allows for various analyses of the model fit. This is shown in the first prompt of Figure 11-16. Additionally, if both the ML and LS methods were successful, the second prompt is issued, allowing the user to select the set of estimates to be used in the analyses. Control then automatically transfers to the Analyses of Model Fit sub-module (Chapter 12). Upon completion, control returns to the Interval Data Model Menu (Section 11.2, step a).

```
   ENTER ONE TO PERFORM AN ANALYSIS OF THE MODEL FIT USING THE PRE-
   DICTIONS OF THIS MODEL; ELSE ZERO.

If ML and LS were successful, then:

   ENTER ONE FOR PREDICTIONS BASED ON MAXIMUM L..ELIHOOD METHOD, OR
   TWO FOR LEAST SQUARES METHOD.

End if
```

FIGURE 11-16. MDLGPO ANALYSES OF MODEL FIT PROMPTS

11.2.3. Non-homogeneous Poisson for Interval Data Model

If the entered model option number is three, then:

a. SMERFS prompts for a flag indicating whether the model assumptions and data requirements are desired (Figure 11-17). If desired, the listing and extra prompts in the figure are output. If the response to the last prompt indicates a desire to abort the model execution, control returns to Section 11.2, step a. (Refer to Paragraph 11.3.3 for details on the prompted input and generated output.)

```
ENTER ONE FOR NHPP MODEL DESCRIPTION; ELSE ZERO.

THE NON-HOMOGENEOUS POISSON MODEL ASSUMPTIONS

  1. THE SOFTWARE IS OPERATED IN A SIMILAR MANNER AS THE ANTICI-
     PATED OPERATIONAL USAGE.

  2. ALL FAULTS ARE EQUALLY LIKELY TO OCCUR  AND ARE INDEPENDENT
     OF EACH OTHER.

  3. EACH FAULT IS OF THE SAME ORDER OF "IMPACT" AS ANY OTHER.

  4. THE  CUMULATIVE NUMBER  OF FAULTS DETECTED AT ANY TIME FOL-
     LOWS A POISSON DISTRIBUTION  WITH MEAN M(T).  THAT  MEAN IS
     SUCH THAT THE EXPECTED  NUMBER OF FAULTS IN  ANY SMALL TIME
     INTERVAL ABOUT T IS PROPORTIONAL  TO THE NUMBER OF UNDETEC-
     TED FAULTS AT TIME T.

  5. THE MEAN IS ASSUMED TO BE A BOUNDED NON-DECREASING FUNCTION
     WITH M(T) APPROACHING IN THE LIMIT, "A" (THE EXPECTED TOTAL
     NUMBER OF FAULTS TO BE, EVENTUALLY, DETECTED IN THE TESTING
     PROCESS), AS THE LENGTH OF TESTING GOES TO INFINITY.

ENTER ONE TO CONTINUE THE DESCRIPTION LIST.
MODEL DATA REQUIREMENTS

  1. THE NUMBER OF FAULTS  DETECTED IN EACH INTERVAL OF TESTING.

  2. THE LENGTHS OF THE VARIOUS TESTING INTERVALS.

     "1 & 2 SHOULD HAVE BEEN ENTERED VIA THE DATA INPUT MODULE."

IF THE ASSUMPTIONS ARE  GENERALLY SATISFIED AND THE APPROPRIATE
DATA ARE AVAILABLE, ENTER ONE TO CONTINUE THE MODEL;  OTHERWISE
ZERO TO RETURN TO THE MENU OF MODELS.
```

FIGURE 11-17. MDLNPI DESCRIPTION PROMPTS AND LIST

b. SMERFS then prompts the user to enter the desired method of estimation (ML or LS) or a value to terminate the model execution (Figure 11-18). If the termination value is entered, control branches to step f.

```
ENTER ONE FOR  MAXIMUM LIKELIHOOD METHOD,  TWO FOR LEAST SQUARES
METHOD, OR THREE TO TERMINATE MODEL EXECUTION.
```

FIGURE 11-18. MDLNPI INPUT PROMPT

c. If the data are not appropriate for this model or the estimate of the total number of faults is less than the observed number, then the appropriate message shown in Figure 11-19 (including the ML or LS indicator) is issued and control returns to step b.

```
**THE DATA ARE NOT APPROPRIATE FOR THE aa MODEL.

**THE ESTIMATE  FOR THE TOTAL  NUMBER OF FAULTS  TO BE DETECTED IN
THE PROGRAM BEFORE  ALL FAULTS ARE UNCOVERED  CAME OUT LESS THAN
THE NUMBER OF FAULTS FOUND TO DATE WITHIN THE aa MODEL.
```

FIGURE 11-19. MDLNPI PROCESSING ERROR MESSAGES

d. Otherwise (if the solution is obtained), the ML or LS estimates are output (Figure 11-20). Within that figure, the upper report (containing the 95-percent confidence intervals) corresponds to the ML estimates and the lower report to the LS estimates.

```
If the ML method was selected, then:

ML MODEL ESTIMATES ARE:
(THE APPROXIMATE 95% CONFIDENCE INTERVALS APPEAR IN PARENTHESES)
  PROPORTIONALITY CONSTANT  eeeeeeeeee ( eeeeeeeee, eeeeeeeee)
  TOTAL NUMBER OF FAULTS    eeeeeeeeee ( eeeeeeeee, eeeeeeeee)
  # OF FAULTS REMAINING     eeeeeeeeee ( eeeeeeeee, eeeeeeeee)

Else, if the LS method was selected, then:

LS MODEL ESTIMATES ARE:
  PROPORTIONALITY CONSTANT  eeeeeeeeee
  TOTAL NUMBER OF FAULTS    eeeeeeeeee
  # OF FAULTS REMAINING     eeeeeeeeee

End if
```

FIGURE 11-20. MDLNPI SUCCESSFUL CONVERGENCE OUTPUT

e. SMERFS then allows for the processing of future predictions to determine the expected performance of the software (Figure 11-21). Upon completion, control returns to step b.

NOTE 1:   The SMERFS program attempts to minimize the number of prompted values by cycling only on the final value (i.e., the value entered for the projected length of the period is prompted only once; the value for the number of faults to discover is prompted until the zero is entered). If changing of the "fixed" value is desired, a zero should be entered to end the current predictions, and then the same prediction option re-selected. Both values will then be prompted.

NOTE 2:   Certain predictions can result in infinite looping; the SMERFS program guards against this condition through an internal program maximum. If that maximum is reached, an error message is issued. Additionally, the user is allowed to change that maximum if it is felt that the maximum is too high or too low (refer to the second predictions of the figure).

ERROR: If the estimate for the (rounded) number of faults remaining is less than one, these future predictions are not allowed and the message shown at the bottom of the figure is issued.

```
  THE AVAILABLE FUTURE PREDICTIONS ARE:
   1) THE NUMBER OF FAULTS EXPECTED IN THE NEXT TESTING PERIOD
   2) THE NUMBER OF PERIODS NEEDED TO DISCOVER THE NEXT M FAULTS
  ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.

   ENTER PROJECTED LENGTH OF THE PERIOD, OR ZERO TO END.
   # OF FAULTS EXPECTED        eeeeeeeeeee ( eeeeeeeee, eeeeeeeee)

   ENTER PROJECTED LENGTH OF THE PERIODS.
   ENTER VALUE OF M (BETWEEN ONE AND eeeeeeeeeee), OR ZERO TO END.
   # OF PERIODS EXPECTED        eeeeeeeeee

If the maximum iterations (1000) is reached, then:

  **# OF PERIODS EXCEEDS        eeeeeeeeeee (PROGRAM MAXIMUM)
    ENTER ONE TO CHANGE THE PROGRAM MAXIMUM; ELSE ZERO.
    ENTER THE NEW VALUE FOR THE PROGRAM MAXIMUM.

End if

**FUTURE PREDICTIONS ARE NOT ALLOWED  BECAUSE THE ESTIMATE FOR THE
  (ROUNDED) NUMBER OF FAULTS REMAINING IS LESS THAN ONE.
```

FIGURE 11-21. MDLNPI FUTURE PREDICTION PROMPTS AND OUTPUT

f.   The user has responded to the prompt in step b with a value equated to termination. Before the return is performed, SMERFS determines if the last execution for either of the methods of estimation was successful; if either was, it allows for various analyses of the model fit. This is shown in the first prompt of Figure 11-22. Additionally, if both the ML and LS methods were successful, the second prompt is issued, allowing the user to select the set of estimates to be used in the analyses. Control then automatically transfers to the Analyses

of Model Fit sub-module (Chapter 12). Upon completion, control returns to the Interval Data Model Menu (Section 11.2, step a).

ENTER ONE TO PERFORM AN ANALYSIS OF THE MODEL FIT USING THE PRE-DICTIONS OF THIS MODEL; ELSE ZERO.

If ML and LS were successful, then:

ENTER ONE FOR PREDICTIONS BASED ON MAXIMUM LIKELIHOOD METHOD, OR TWO FOR LEAST SQUARES METHOD.

End if

FIGURE 11-22. MDLNPI ANALYSES OF MODEL FIT PROMPTS

11.2.4 Schneidewind's Maximum Likelihood Model

If the entered model option number is four, then:

a. SMERFS prompts for a flag indicating whether the model assumptions and data requirements are desired (Figure 11-23). If desired, the listing and extra prompts in the figure are output. If the response to the last prompt indicates a desire to abort the model execution, control returns to Section 11.2, step a. (Refer to Paragraph 11.3.4 for details on the prompted input and generated output.)

```
ENTER ONE FOR SCHNEIDEWIND MODEL DESCRIPTION; ELSE ZERO.

THE SCHNEIDEWIND MODEL ASSUMPTIONS

  1. THE SOFTWARE IS OPERATED IN A SIMILAR MANNER AS THE ANTICI-
     PATED OPERATIONAL USAGE.

  2. ALL FAULTS ARE EQUALLY LIKELY TO OCCUR  AND ARE INDEPENDENT
     OF EACH OTHER.

  3. EACH FAULT IS OF THE SAME ORDER OF "IMPACT" AS ANY OTHER.

  4. THE MEAN NUMBER OF DETECTED FAULTS DECREASES FROM ONE TEST-
     ING INTERVAL TO THE NEXT.

  5. THE FAULT CORRECTION  RATE IS PROPORTIONAL TO THE NUMBER OF
     FAULTS TO BE CORRECTED.

  6. ALL TESTING PERIODS ARE OF THE SAME LENGTH.

ENTER ONE TO CONTINUE THE DESCRIPTION LIST.
  7. THE RATE OF  FAULT DETECTION IS  PROPORTIONAL TO THE NUMBER
     OF FAULTS WITHIN THE PROGRAM AT THE TIME OF TEST. THE FAULT
     DETECTION PROCESS IS A NON-HOMOGENEOUS POISSON PROCESS WITH
     AN EXPONENTIALLY DECREASING FAILURE RATE.

MODEL DATA REQUIREMENTS

  1. THE NUMBER OF FAULTS  DETECTED IN EACH INTERVAL OF TESTING.
     THE DATA SHOULD HAVE BEEN ENTERED VIA THE INPUT MODULE.

IF THE ASSUMPTIONS ARE  GENERALLY SATISFIED AND THE APPROPRIATE
DATA ARE AVAILABLE, ENTER ONE TO CONTINUE THE MODEL;  OTHERWISE
ZERO TO RETURN TO THE MENU OF MODELS.
```

FIGURE 11-23. MDLSDW DESCRIPTION PROMPTS AND LIST

b. SMERFS then permits a description of the three Treatment types for this model by issuing the prompt shown in Figure 11-24. If the response entered indicates that the additional information is desired, the list is output.

```
ENTER ONE FOR DESCRIPTION OF TREATMENT TYPES; ELSE ZERO.

TREATMENT 1 - UTILIZE ALL FAULT COUNTS FROM EACH OF THE TESTING
              PERIODS.

TREATMENT 2 - IGNORE FAULT COUNTS FROM THE  FIRST "S-1" TESTING
              PERIODS  AND USE  ONLY THE FAULT COUNTS FROM PER-
              IOD "S" THROUGH THE TOTAL NUMBER OF PERIODS.

TREATMENT 3 - USE CUMULATIVE NUMBER OF FAULTS FROM  PERIODS ONE
              THROUGH "S-1" AND THE INDIVIDUAL COUNTS FROM PER-
              IOD "S" THROUGH THE TOTAL NUMBER OF PERIODS.
```

FIGURE 11-24. MDLSDW TREATMENT DESCRIPTION PROMPT AND LIST

c. SMERFS then allows for the investigation of the "optimum S" (Reference 6) through the first prompt of Figure 11-25. If the response entered indicates that this additional analysis is desired, then SMERFS prompts for the range over which S is to be processed. As shown in the figure, a table of the resulting ALPHA, BETA, WLS, MSE_F, and MSE_T values for each value of S within the range will be generated. (Note, if the calculation for the MSE_T results in the attempt to take the log of a non-positive number, that calculation is terminated and the field is left blank.) The optimum S based on the weighted sums-of-squares is the one resulting in the smallest value. The optimum S for either MSE_F or MSE_T (the preferred methods) is the one resulting also in the smallest value for the chosen criteria. (Refer to Paragraph 11.3.4 for specific information on this selection process.)

```
ENTER ONE TO INVESTIGATE FOR THE OPTIMUM S (USING TREATMENT TYPE
NUMBER 2); ELSE ZERO TO CONTINUE WITH THE MODEL EXECUTION.

If an affirmative response was entered, then:

ENTER RANGE OVER WHICH S  SHOULD BE TESTED.  NOTE, AN EXECUTION
ON A GIVEN S WHICH FAILED THE CONVERGENCE CRITERIA  WILL NOT BE
INCLUDED IN THE FOLLOWING RESULTS TABLE.  THE OPTIMUM S FOR EI-
THER MSE-F OR MSE-T IS THE ONE  RESULTING IN THE SMALLEST VALUE
FOR YOUR CHOSEN CRITERIA.

S     BETA        ALPHA        WLS          MSE-F         MSE-T
===  ==========  ==========  ==========  ===========  ===========
iii  eeeeeeeeeee eeeeeeeeeee eeeeeeeeeee eeeeeeeeeee  eeeeeeeeeee
 .        .           .           .           .            .
 .        .           .           .           .            .
iii  eeeeeeeeeee eeeeeeeeeee eeeeeeeeeee eeeeeeeeeee  eeeeeeeeeee

ENTER ONE TO INVESTIGATE ANOTHER RANGE FOR S; ELSE ZERO.

End if
```

FIGURE 11-25. MDLSDW OPTIMUM S PROMPTS AND OUTPUT

d. SMERFS prompts the user to enter the desired Treatment number or a value to terminate this model execution (Figure 11-26). If the termination value is entered, control branches to step h. If a Treatment type is selected, SMERFS prompts for the value of the variable "S" (if the Treatment type was two or three).

```
ENTER DESIRED MODEL TREATMENT NUMBER, OR FOUR TO TERMINATE MODEL
EXECUTION.

If the Treatment type is two or three, then:

   ENTER ASSOCIATED VALUE OF S (LESS THAN THE NUMBER OF PERIODS).

End if
```

FIGURE 11-26. MDLSDW INPUT PROMPTS

e. If the data are not appropriate for this model or the estimate of the total number of faults is less than the observed number, then the message shown in Figure 11-27 (including the Treatment type number) is issued and control returns to step d.

```
**THE DATA ARE NOT APPROPRIATE FOR THE TREATMENT NUMBER i MODEL.

**THE ESTIMATE  FOR THE TOTAL  NUMBER OF FAULTS  TO BE DETECTED IN
  THE PROGRAM BEFORE  ALL FAULTS ARE UNCOVERED  CAME OUT LESS THAN
  THE NUMBER OF FAULTS FOUND TO DATE WITHIN THE TREATMENT NUMBER i
  MODEL.
```

FIGURE 11-27. MDLSDW PROCESSING ERROR MESSAGES

f. Otherwise (if the solution is obtained), the estimates are output, including the Treatment type number (Figure 11-28).

```
TREATMENT i MODEL ESTIMATES ARE:
   BETA                          eeeeeeeeeee
   ALPHA                         eeeeeeeeeee
   TOTAL NUMBER OF FAULTS        eeeeeeeeeee

If the Treatment type is two, then:

   PLUS THOSE SKIPPED      eeeeeeeeeee IN PERIODS 1 THROUGH iii

End if
```

FIGURE 11-28. MDLSDW SUCCESSFUL CONVERGENCE OUTPUT

```
   # OF FAULTS REMAINING        ●●●●●●●●●●
   WEIGHTED SUMS-OF-SQUARES
     BETWEEN PREDICTED AND
     OBSERVED FAULTS            ●●●●●●●●●●
   MEAN SQUARE ERROR FOR
     CUMULATIVE FAULTS          ●●●●●●●●●●

If the calculation was not ended by a non-positive value, then:

   MEAN SQUARE ERROR FOR
     TIME TO NEXT FAILURE       ●●●●●●●●●●

End if
```

FIGURE 11-28. MDLSDW SUCCESSFUL CONVERGENCE OUTPUT (Continued)

g.　SMERFS then allows for the processing of future predictions to determine the expected performance of the software (Figure 11-29). Upon completion, control returns to step d.

NOTE:　If the prediction for the number of periods cannot be made for the entered value for the number of faults, the shown error message is issued.

ERROR:　If the estimate for the (rounded) number of faults remaining is less than one, these future predictions are not allowed and the message shown at the bottom of the figure is issued.

```
   THE AVAILABLE FUTURE PREDICTIONS ARE:
    1) THE NUMBER OF FAULTS EXPECTED IN THE NEXT TESTING PERIOD
    2) THE NUMBER OF PERIODS NEEDED TO DISCOVER THE NEXT M FAULTS
   ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.

    ENTER NUMBER OF PERIODS TO EXAMINE, OR ZERO TO END.
    # OF FAULTS EXPECTED        ●●●●●●●●●●

    ENTER VALUE OF M (BETWEEN ONE AND ●●●●●●●●●●), OR ZERO TO END.
    # OF PERIODS EXPECTED       ●●●●●●●●●●

If the prediction could not be made for the input M value, then:

** THE ESTIMATE CANNOT BE MADE FOR THE SPECIFIED M VALUE.

End if

**FUTURE PREDICTIONS ARE NOT ALLOWED  BECAUSE THE ESTIMATE FOR THE
  (ROUNDED) NUMBER OF FAULTS REMAINING IS LESS THAN ONE.
```

FIGURE 11-29. MDLSDW FUTURE PREDICTION PROMPTS AND OUTPUT

h.   The user has responded to the prompt in step d with a value equated to termination. Before the return is performed, SMERFS determines if the last execution of any of the three Treatment types was successful; if any were, it allows for various analyses of the model fit. This is shown in the first prompt of Figure 11-30. Additionally, if more than one Treatment type were successful, the second prompt is issued, allowing the user to select the set of estimates to be used in the analyses. Control then automatically transfers to the Analyses of Model Fit sub-module (Chapter 12). Upon completion, control returns to the Interval Data Model Menu (Section 11.2, step a).

NOTE: For Treatment type two, the first S-1 intervals are eliminated from the observed data vector. For treatment type three, the vector is reduced by S-2 predictions, where the first S-1 intervals (of observed fault counts) are summed on interval one, and intervals two through S-1 are eliminated from the observed data vector. This is reflected by the final message of the figure.

```
   ENTER ONE TO PERFORM AN ANALYSIS OF THE MODEL FIT USING THE PRE-
   DICTIONS OF THIS MODEL; ELSE ZERO.

If more than one Treatment type were successful, then:

   ENTER TREATMENT NUMBER BY WHICH THE PREDICTIONS ARE TO BE MADE.

End if

If the Treatment type is two or three, then:

   NOTE: THE STARTING INDEX OF THE DATA IS SHIFTED BY iii UNITS TO
   REFLECT TREATMENT TYPE i

End if
```

FIGURE 11-30. MDLSDW ANALYSES OF MODEL FIT PROMPTS

11.2.5 S-Shaped Reliability Growth Model

If the entered model option number is five, then:

a.   SMERFS prompts for a flag indicating whether the model assumptions and data requirements are desired (Figure 11-31). If desired, the listing and extra prompts in the figure are output. If the response to the last prompt indicates a desire to abort the model execution, control returns to Section 11.2, step a.   (Refer to Paragraph 11.3.5 for details on the generated output.)

```
ENTER ONE FOR S-SHAPED MODEL DESCRIPTION; ELSE ZERO.

THE S-SHAPED RELIABILITY GROWTH MODEL ASSUMPTIONS

  1. THE SOFTWARE IS OPERATED IN A SIMILAR MANNER AS THE ANTICI-
     PATED OPERATIONAL USAGE.

  2. ALL FAULTS ARE EQUALLY LIKELY TO OCCUR  AND ARE INDEPENDENT
     OF EACH OTHER.

  3. EACH FAULT IS OF THE SAME ORDER OF "IMPACT" AS ANY OTHER.

  4. THE  INITIAL  FAULT  CONTENT OF  THE  SOFTWARE  SYSTEM IS A
     RANDOM VARIABLE.

  5. THE TIME BETWEEN FAILURES (K - 1) AND K DEPENDS ON THE TIME
     TO FAILURE (K - 1).

  6. FAULTS ARE CORRECTED  IMMEDIATELY  WITHOUT  INTRODUCING NEW
     ONES.

ENTER ONE TO CONTINUE THE DESCRIPTION LIST.
MODEL DATA REQUIREMENTS

  1. THE NUMBER OF FAULTS  DETECTED IN EACH INTERVAL OF TESTING.

  2. THE LENGTHS OF THE VARIOUS TESTING INTERVALS.

    "1 & 2 SHOULD HAVE BEEN ENTERED VIA THE DATA INPUT MODULE."

IF THE ASSUMPTIONS ARE  GENERALLY SATISFIED AND THE APPROPRIATE
DATA ARE AVAILABLE, ENTER ONE TO CONTINUE THE MODEL;  OTHERWISE
ZERO TO RETURN TO THE MENU OF MODELS.
```

FIGURE 11-31. MDLESH DESCRIPTION PROMPTS AND LIST

b.   If the data are not appropriate for this model or the estimate of the total number of faults is less than the observed number, then the message shown in Figure 11-32 is issued and control branches to step e.

```
**THE DATA ARE NOT APPROPRIATE FOR THE MODEL.

**THE ESTIMATE  FOR THE TOTAL  NUMBER OF FAULTS  TO BE DETECTED IN
  THE PROGRAM BEFORE  ALL FAULTS ARE UNCOVERED  CAME OUT LESS THAN
  THE NUMBER OF FAULTS FOUND TO DATE WITHIN THE MODEL.
```

FIGURE 11-32. MDLESH PROCESSING ERROR MESSAGES

c.   Otherwise (if the solution is obtained), the estimates are output (Figure 11-33).

```
MODEL ESTIMATES ARE:
(THE APPROXIMATE 95% CONFIDENCE INTERVALS APPEAR IN PARENTHESES)
 PROPORTIONALITY CONSTANT  eeeeeeeeeee ( eeeeeeeeee, eeeeeeeeee)
 TOTAL NUMBER OF FAULTS    eeeeeeeeeee ( eeeeeeeeee, eeeeeeeeee)
 # OF FAULTS REMAINING     eeeeeeeeeee ( eeeeeeeeee, eeeeeeeeee)
```

FIGURE 11-33. MDLESH SUCCESSFUL CONVERGENCE OUTPUT

d.   SMERFS then allows for the processing of future predictions to determine the expected performance of the software (Figure 11-34).

   NOTE: Certain predictions can result in infinite looping; the SMERFS program guards against this condition through an internal program maximum. If that maximum is reached, an error message is issued. Additionally, the user is allowed to change that maximum if it is felt that the maximum is too high or too low (refer to the second predictions of the figure).

   ERROR: If the estimate for the (rounded) number of faults remaining is less than one, these future predictions are not allowed and the message shown at the bottom of the figure is issued.

```
THE AVAILABLE FUTURE PREDICTIONS ARE:
 1) THE NUMBER OF FAULTS EXPECTED IN THE NEXT TESTING PERIOD
 2) THE NUMBER OF PERIODS NEEDED TO DISCOVER THE NEXT M FAULTS
 3) THE SOFTWARE RELIABILITY IN THE NEXT PERIOD
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.

ENTER PROJECTED LENGTH OF THE PERIOD, OR ZERO TO END.
 # OF FAULTS EXPECTED      eeeeeeeeeee
```

FIGURE 11-34. MDLESH FUTURE PREDICTION PROMPTS AND OUTPUT

```
     ENTER PROJECTED LENGTH OF THE PERIODS.
     ENTER VALUE OF M (BETWEEN ONE AND ●●●●●●●●●●●), OR ZERO TO END.
     # OF PERIODS EXPECTED      ●●●●●●●●●●●

If the maximum iterations (1000) is reached, then:

 **# OF PERIODS EXCEEDS      ●●●●●●●●●●● (PROGRAM MAXIMUM)
    ENTER ONE TO CHANGE THE PROGRAM MAXIMUM; ELSE ZERO.
    ENTER THE NEW VALUE FOR THE PROGRAM MAXIMUM.

End if

    ENTER PROJECTED LENGTH OF THE PERIOD, OR ZERO TO END.
    PROB. OF OPERATION WITH-
     OUT FAILURE IN PERIOD     ●●●●●●●●●●●  .

 **FUTURE PREDICTIONS ARE NOT ALLOWED  BECAUSE THE ESTIMATE FOR THE
    (ROUNDED) NUMBER OF FAULTS REMAINING IS LESS THAN ONE.
```

FIGURE 11-34. MDLESH FUTURE PREDICTION PROMPTS AND OUTPUT (Continued)

e. SMERFS determines if the execution was successful. If it was, it allows for various analyses of the model fit. This is shown in the prompt of Figure 11-35. Control then automatically transfers to the Analyses of Model Fit sub-module (Chapter 12). Upon completion, control returns to the Interval Data Model Menu (Section 11.2, step a).

```
    ENTER ONE TO PERFORM AN ANALYSIS OF THE MODEL FIT USING THE PRE-
    DICTIONS OF THIS MODEL; ELSE ZERO.
```

FIGURE 11-35. MDLESH ANALYSES OF MODEL FIT PROMPT

11.3 MODEL OUTPUTS AND CONSIDERATIONS

The reader is directed to the references for a detailed description of the model parameters and outputs covered in this chapter. Reference 2 is especially applicable unless indicated otherwise in this section. This section (as did Section 10.3), discusses the meaning of any required inputs and displayed outputs. Considerations for requested inputs are also discussed. One of the biggest changes from SMERFS version 3 to 4 (thus incorporated in version 5) is that most of the models no longer require the input of the starting values for the optimization procedures for model parameter estimation. The models using the Dekker-Brent optimization procedure have built-in calculations for such values and, as a result, no user input is required. The only models not employing this technique in this section are the Generalized Poisson Model and the Brooks and Motley's Discrete Software Reliability Model. These models employ the Trust Region methodology. This technique will still, however, determine starting values or let the user override them and input different starting values.

11.3.1 Brooks and Motley's Discrete Software Reliability Model

If the user indicates to the program that not all of the code was under test in each test period, the user will have to input two additional quantities for each test period. The first is the fraction of the code being tested for the given period, and the second is the cumulative total number of faults detected in this fractional part over the past testing periods. (Note that for the first testing period, only the fraction of code under test is requested as the value for the number of faults detected previously in this section of the code is set automatically by the program to zero.)

A suggested range of values for ALPHA (the probability of correcting faults in the program without inserting new ones) is 0.85 to 0.95 if no prior knowledge is available. If the user decides to override the suggested initial estimates for the probability of detecting faults and the total number of faults, the user estimates must be in the ranges 1.0E-07 to 9.99E-01 and the total number of faults found to date to 1.0E+07, respectively.

The program gives estimates of the total number of faults, the number of remaining faults, and the probability of fault detection. In addition, the program allows the user to estimate the expected number of faults in the next testing period and the number of periods required to discover the next M faults (Figure 11-8). For the first, the user must enter the length of the testing period (see Paragraph 11.3.3) and the fraction of the code that will be tested. For example, if a "1" was entered in the original data entry to represent a month's worth of testing and the user is particularly interested in a 2-week testing period, then enter 2/4 = 0.5. If the full program was to be under test, enter a "1" for the fractional part of the software. (If this value is entered, the user should enter the total number of faults that have been found to date for the entire program, after the prompt asking for the number of faults found in this section of code under test is given.)

For the second prediction, the user is again prompted for the length of the testing periods, the fraction of code that will be tested, and the number of faults that have been found to date in this section of code, as well as the desired number of faults to be found. The same comments as given for the first prediction estimate apply for this one as well.

11.3.2 Generalized Poisson Model

The first prompt, after the model assumptions, asks if any faults detected in one testing period were corrected in a later period. For example, five faults were detected in the first period, but only three of them were corrected during this time frame. If this is the situation, the user enters the number of faults actually corrected during each testing period, following the prompt shown in Figure 11-11 by the computer.

The user then has an option for the type of weighting function to assign to the lengths, [X(I)] of the respective testing periods (Figure 11-12 and Reference 2). If the ALPHA input option is selected, the larger the value of ALPHA, the greater the weight applied to the testing period. Negative values for ALPHA also work. Usually, a value of 1.0 will be tried first, followed by 2.0, 0.5, 0.1, and finally -1.0. If the user desires to estimate ALPHA (increasing the number of estimated parameters to 3), the data base should be fairly large (50 or more values). If ALPHA is to be estimated, the Trust procedure will be used, necessitating the user to make a decision whether to use or override initial program calculated estimates for the total number of faults and ALPHA. The estimate for the total number of faults should be larger than the number found to date and less than $1.0E+07$. The initial estimate for ALPHA must be between 0.0 and $1.0E+07$.

The program gives estimates of the total number of faults, the number of remaining faults, ALPHA if estimated, and the proportionality constant of the model, along with the associated 95-percent confidence intervals. The user has the option of predicting the number of faults expected in the next testing period and/or the number of periods needed to discover the next M faults. In either case the user must enter the projected length of the testing period. As before, if "1" was entered in the original data set to represent a month's worth of testing and the user is interested in a 3-month period, the user enters "3". The one prediction will give how many faults are estimated to be found during this time period, while the other will give how many periods of the entered length are required to find the next M (user input) faults.

11.3.3 Non-homogeneous Poisson Model for Interval Data

The program gives estimates of the proportionality constant, the total number of faults, and the number of remaining faults, along with the associated 95-percent confidence intervals. For prediction purposes, the user can estimate the number of faults expected in the next period and/or the number of periods required to discover the next M faults. The same comments as applied to the Brooks and Motley models (Paragraph 11.3.1) and the Generalized Poisson model (Paragraph 11.3.2) on the meaning of the required inputs for these two prediction estimates apply here.

11.3.4 Schneidewind's Maximum Likelihood Model

The user must select the appropriate Treatment type and if type 2 or 3 is selected, a value for "S" must be entered. The value for S determines how much weight should be placed upon the initial testing periods. If the user feels that the earlier testing periods are no different than the later ones, Treatment number 1 should be picked. If, however, the periods are significantly different (e.g., too few faults detected, learning curve phenomena observed, etc.), then the data can be treated in one of two ways.

The earlier testing periods can be either discarded by using Treatment number 2 or combined by using Treatment number 3. The value of S determines this transition point.

To help determine the optimal value of S, two selection criteria have been incorporated into this new version of SMERFS to reflect Dr. Schneidewind's recent work in the area (Reference 9). The criteria are the Mean-Square-Error for cumulative faults (MSE_F) and for time to next failure (MSE_T). Both look at the average squared error difference between functions of the actual data and those values estimated by the model. One uses the actual cumulative fault counts and those predicted by the model (MSE_F). The other uses the predicted future failure counts and those generated by the model (MSE_F). Ideally for either of the selected criteria, one is looking for the optimal value of S that minimizes these differences. The user needs to ensure, by varying the range of S values, that the optimal S has been achieved; however, Dr. Schneidewind's work has shown that the first local minimum found may be satisfactory. The weighted sums-of-squares is a third criteria that can also be used to determine the optimal S. The optimal value for this criteria is the one that minimizes the weighted least squares function. Of the three criteria, the preferred method is to use either the MSE_F or the MSE_T.

For the selected model and associated value of S, the program gives estimates of the model parameters ALPHA, the model parameter BETA, the total number of faults, the number of remaining faults, and the three previously defined values. For the meaning of the model parameters, refer to Reference 2.

The same prediction statistics as considered by other models (refer to Paragraphs 11.3.1 and 11.3.2) are generated by Schneidewind's model. Therefore, the same comments made in those paragraphs are applicable here for both the requested inputs and associated outputs.

11.3.5 S-Shaped Reliability Growth Model

The program gives estimates of the proportionality constant, the total number of faults, and the number of remaining faults. The associated 95-percent confidence intervals are also given. For a description of the model, see Reference 6. This model is a good candidate for fitting a data set if a "learning curve" scenario applies (i.e., the number of faults found slowly ramps up as the testers become familiar with the code, accelerates quickly up, and then levels off as the remaining faults become more difficult to find).

As in previous models, the user can obtain the expected number of errors in the next testing period and/or the number of periods to uncover the next M faults. Considerations concerning the length are the same as given previously (see Paragraphs 11.3.1 and 11.3.2 for example). A third reliability indicator is also provided. It is the software reliability for the next testing length. After entering the length, the user is shown an estimate of the probability that the software will operate without failure for that time frame. An example would be if the user had entered the time intervals of the original data set to represent a month and the user entered a six for the prompted length, the program would give an estimate that the software would operate without failure for a period of six months. These statistics can be extremely useful in doing tradeoff analyses to determine optimal release time or determining when an existing operational program should be rewritten.

CHAPTER 12

ANALYSES OF MODEL FIT SUB-MODULE

12.1 INTRODUCTION

The Analyses of Model Fit sub-module of the Model Execution modules (Chapters 10 and 11) provides four methods for determining how well a model fits the data. This entire area of validation of a model fit is of the utmost importance; predictions and estimations of a particular model should never be taken as reflective of the data until some (all) of these analyses have been conducted.

For interval data, the chi-square Goodness-of-Fit statistic can be obtained. The computed values (in conjunction with a chi-square table) provide a firm mathematically and statistically based analysis of the data. For execution time data, the Kolmogorov Distance is calculated and the distance is internally evaluated to determine if there is a significant amount of randomness in the residuals to indicate that the model may fit the data. (Refer to Section 12.3 for more details on the Kolmogorov Distance.) The remaining three analyses are more subjective, calling on the user to determine if patterns exist in the predictions. These include data listings of the original, predicted, and residuals data, plots of the original and predicted data, and plots of the residuals. One is looking for both good tracking of the observed values by the model and no apparent "trend" in the plot of the residuals. If the model is adequately capturing most of the variation in the data, what is left should be primarily "noise". Thus, no pattern should be present.

The plots are the result of an internal line printer plotter. The internal plotter produces very crude graphs to assist the user in quick interactive examinations of the data and model fit. It is, however, highly recommended that users make use of the optional Plot file (Chapter 2, step d). Examples of this file can be found in Appendixes C and D.

12.2 EXECUTION FLOW

This section explains the prompts and inputs for the analyses of the model fit portion of SMERFS. The placement of and the print in the figures conform to the strategy introduced in Sections 1.5 and 1.6.

    a.   Analyses Option Selection

        The program prompts the user for the type of analysis to be performed (Figure 12-1). If an invalid option number is entered, the same list and second prompt are output.

```
ENTER ANALYSES OPTION, OR ZERO FOR A LIST.
THE AVAILABLE ANALYSES OPTIONS ARE:
 1 GOODNESS-OF-FIT TESTS
 2 ORIGINAL, PREDICTED, AND RESIDUAL DATA LISTINGS
 3 PLOT OF ORIGINAL AND PREDICTED DATA
 4 PLOT OF THE RESIDUAL DATA
 5 RETURN TO THE MODEL EXECUTION MENU
ENTER ANALYSES OPTION.
```

FIGURE 12-1. ANALYSES OF MODEL FIT MENU

b.   Goodness-of-Fit Test for Execution Time Data (Kolmogorov Distance)

If the entered analysis option number is one and TBF data were analyzed (data type was entered as a one, two, or three), SMERFS issues one of two possible messages (Figure 12-2) reflecting if the model may provide an adequate fit. (Refer to Section 12.3 for more details on the Kolmogorov Distance and its utility.) Upon completion, control returns to step a.

```
If the computed distance is significant, then:

   THE KOLMOGOROV DISTANCE IS  ●●●●●●●●●●●●●●●, BASED UPON iii DATA
   POINTS.  THAT DISTANCE IS SIGNIFICANT AT THE 0.05 LEVEL; THERE-
   FORE, IT APPEARS THE MODEL MAY NOT PROVIDE AN ADEQUATE FIT.

Else, if the model may provide an adequate fit, then:

   THE KOLMOGOROV DISTANCE IS  ●●●●●●●●●●●●●●, BASED UPON iii DATA
   POINTS.  THAT DISTANCE  IS NOT  SIGNIFICANT AT THE 0.05  LEVEL;
   THEREFORE, IT APPEARS THE MODEL MAY PROVIDE AN ADEQUATE FIT.

End if
```

FIGURE 12-2. KOLMOGOROV DISTANCE OUTPUT

c.   Goodness-of-Fit Test for Interval Data (Chi-Square)

If the entered analysis option number is one and interval data were analyzed (data type was entered as a four), SMERFS prompts for the cell combination frequency number to be used in constructing the chi-square interval partitions (Figure 12-3). If the last chi-square interval could not be made to contain the user-specified cell frequency, the warning lines from the figure are output, containing the value of the last chi-square interval. The actual chi-square statistic and the computed degrees-of-freedom are then output, and the user is allowed to repeat the execution with a different cell combination frequency. (Refer to Section 12.3 for a description of these values.) Upon completion, control returns to step a.

ERROR: If the calculated degrees-of-freedom was computed to be less than one, the
message shown at the bottom of the figure is issued.

```
ENTER THE CELL COMBINATION FREQUENCY (THE STANDARD IS FIVE), OR
A MINUS ONE TO INDICATE NO CELL COMBINATIONS.

If the cell combination could not be achieved, then:

   THE CELL COMBINATION  WAS NOT ACHIEVED  FOR THE  LAST INTERVAL;
   THE GREATEST POSSIBLE VALUE WAS eeeeeeeeeeeee.

End if

   THE CHI-SQUARE STATISTIC  IS eeeeeeeeeeeeee WITH iiiii DEGREES-
   OF-FREEDOM.

**THE CHI-SQUARE STATISTIC CANNOT BE CALCULATED;  THE DEGREES-OF-
   FREEDOM WAS CALCULATED TO BE LESS THAN ONE.

ENTER ONE TO TRY ANOTHER COMBINATION FREQUENCY; ELSE ZERO.
```

FIGURE 12-3. CHI-SQUARE PROMPTS AND OUTPUT

d.   Original, Predicted, and Residual Data Listing

If the entered analysis option number is two, the listing (containing the original, predicted,
and residual data) is output (Figure 12-4) and control returns to step a.

```
NUMBER      ORIGINAL DATA      PREDICTED DATA      RESIDUAL DATA
======      ================   ================    ==============
 iii        eeeeeeeeeeeeee     eeeeeeeeeeeeee      eeeeeeeeeeeee
  .               .                  .                   .
  .               .                  .                   .
 iii        eeeeeeeeeeeeee     eeeeeeeeeeeeee      eeeeeeeeeeeee
```

FIGURE 12-4. LIST ORIGINAL, PREDICTED, AND RESIDUAL VALUES

e.   Plot of Original and Predicted Data

If the entered analysis option number is three, then SMERFS prompts for the plot title
(Figure 12-5). For correct centering on the plot, the title should be centered in the
30-character field.

The plot is then generated (Figure 12-5), including the user-specified title and the program-
determined axis labels. The units for the TBF measurement will also be placed on the plot
as a second y-axis label. This second field will be left blank for interval data.

The plotter can only reflect a maximum of 50 elements on the x-axis. The message shown at the bottom of the figure not only provides for a pause between plots, but also allows for termination of the plotting. After the plotting, control returns to step a.

NOTE: The minimum and maximum values for the y-axis are defined over all values to be plotted, not just those reflected in the plot of 50 points.

```
ENTER A PLOT TITLE (UP TO 30 CHARACTERS).

                    aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa

●●●●●●●●●●●●●●  !
               !
               !
               !         *  =  original data
               !         P  =  predicted value
               !         $  =  * and P too close to distinguish on plot
               !
   aaaaaa       !
   aaaaaaa      !
               !
               !
               !
               !
               !
●●●●●●●●●●●●●●  !
               +---------+---------+---------+---------+---------+
      iii          iii       iii       iii       iii       iii

                         aaaaaaaaaa

ENTER ONE TO VIEW THE NEXT SECTION; ELSE ZERO TO EXIT PLOTTER.
```
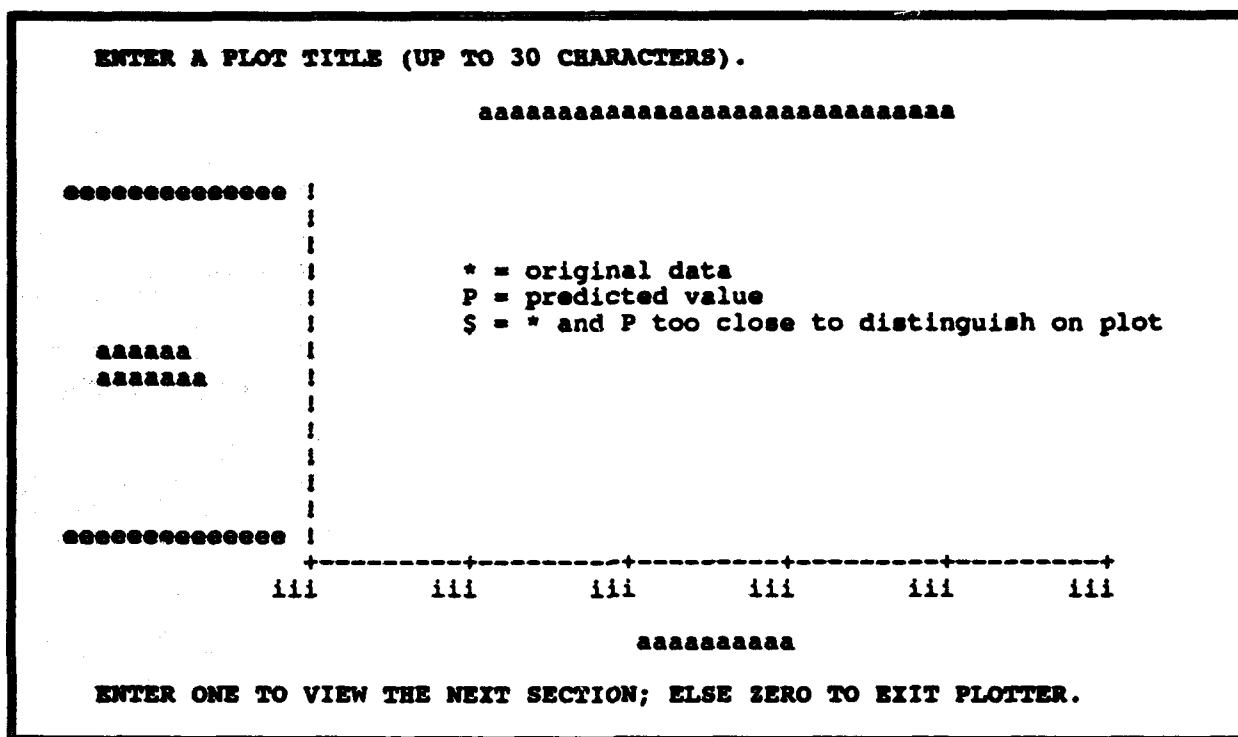
FIGURE 12-5. ORIGINAL AND PREDICTED PLOT FORMAT AND PROMPTS

f.   Plot of the Residual Data

If the entered analysis option number is four, then SMERFS prompts for the plot title (Figure 12-6). For correct centering on the plot, the title should be centered in the 30-character field. Additionally, if the sample size is greater than six, SMERFS prompts the user to determine if smoothing of the residual data is desired with the second prompt shown in Figure 12-6. The smoothing technique is described in Reference 7.

The plot is then generated (Figure 12-6), including the user-specified title and the program-determined axis labels. The units for the TBF measurement will also be placed on the plot as a second y-axis label. This second field will be left blank for interval data.

The plotter can only reflect a maximum of 50 elements on the x-axis. The message shown at the bottom of the figure not only provides for a pause between plots, but also allows for termination of the plotting. After the plotting, control returns to step a.

NOTE: The minimum and maximum values for the y-axis are defined over all values to be plotted, not just those reflected in the plot of 50 points.

```
ENTER A PLOT TITLE (UP TO 30 CHARACTERS).

ENTER ONE TO SMOOTH THE  RESIDUALS; ELSE ZERO.

                    aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa

eeeeeeeeeeeee I
              I
              I
              I        * = difference between the original and the
              I            predicted values from the model
              I
   aaaaaa     I
   aaaaaaa    I
              I
              I
              I
              I
              I
eeeeeeeeeeeee I
              +---------+---------+---------+---------+---------+
       iii       iii       iii       iii       iii       iii

                         aaaaaaaaaa

ENTER ONE TO VIEW THE NEXT SECTION; ELSE ZERO TO EXIT PLOTTER.
```

FIGURE 12-6. RESIDUAL PLOT FORMAT AND PROMPTS

g. Return to the Main Module (and Placing Data on the Plot File)

If the entered analysis option number is five, then the analyses of model fit is over and the user has requested a return to the Model Menu (Chapter 10, step b for execution time data or Chapter 11, step a for interval data). Before the return is performed, SMERFS checks to see if the optional Plot file was established (Chapter 2, step d). If established, SMERFS allows the user the opportunity to place the Goodness-of-Fit statistic and the pertinent data on the file (Figure 12-7). If the response indicates a desire to place these data on the file, a 40-character title is then requested. Then the title, axis labels, and all data are written to the file. (Refer to Section 13.3 for content description and Appendixes C and D for examples.) Upon completion, control returns to the Model Menu (Chapter 10, step b for execution time data or Chapter 11, step a for interval data).

```
If the optional SMERFS plot file was established, then:

  ENTER ONE TO PLACE THE PLOT AND GOODNESS-OF-FIT STATISTIC ON THE
  OPTIONAL SMERFS PLOT FILE; ELSE ZERO.

 If a positive response was input, then:

  PLEASE ENTER A PLOT TITLE FOR ALL DATA (UP TO 40 CHARACTERS).

 End if

End if
```

FIGURE 12-7. PLACING THE DATA ON THE SMERFS PLOT FILE

12.3 VALUES DESCRIPTIONS

The Kolmogorov distance is a measure of the discrepancy between the sample cumulative distribution function and the model's. It is the maximum "gap" between the sample's cumulative distribution function as represented by a step function and the theoretical one based upon the model. If this difference is too large, the model may be inadequate. Note, the Kolmogorov distance is not a true K-S distance test as model parameters have been replaced by their estimates. The distributional assumptions of the K-S distance may therefore not be satisfied. The user needs to keep in mind that only an approximate test is being performed. Past studies have shown, for various distributions, that the actual significance level of the test may be smaller than what is used. This tends to lead to conservative tests (i.e., rejecting the model adequacy when the model is appropriate significantly fewer times than normal).

For the implementation of the chi-square Goodness-of-Fit test within the program, SMERFS allows the user to input a value such that each of the expected cell frequencies will be greater than or equal to that value (Figure 12-3). Suggested values are -1.0 (each data point is treated separately, i.e., no combinations are formed) and 5.0 (the usual value seen in the literature on the chi-square test). The chi-square test (Reference 8) rejects the null hypothesis that the data follow the fitted model if the value of the chi-square statistic is larger than the upper tail $X^2(1 - \alpha, df)$ of a chi-square distribution with degrees-of-freedom of df and a significance level of α. For example, if $\alpha = 0.05$ (it is acceptable to take a chance of 0.05 of rejecting the null hypothesis when it is true), df = 10, and the output chi-square value is 14.62; then $X^2(1 - \alpha, df) = X^2(0.95, 10) = 18.3$, so the null hypothesis would be accepted. The data do tend to follow the model.

CHAPTER 13

SMERFS TERMINATION AND FOLLOWUP

13.1 INTRODUCTION

If the entered Main module option number is nine, SMERFS responds with a message of program termination (Figure 13-1) and returns the user to the command mode of the terminal.

```
THE SMERFS EXECUTION HAS ENDED.
```

FIGURE 13-1. SMERFS TERMINATION

13.2 COMMANDS

The followup commands only pertain to executions in which output files were generated. These include the data file(s), the History file, and the Plot file. If these files were not generated, this section may be ignored.

If output files were generated, probably some additional instructions from the operating system level of the target computer are required. Although the specific commands vary from computer-to-computer, the basic actions are placing the developed files on a permanent storage media and removing any redundant files from that area. The first key question to answer prior to session termination is "Are the data, History, and Plot files in an area that will not be lost when the session is terminated?" For the CDC 170/875 (which has local and permanent files), this implies that the local files (generated by the program) must be "saved" as permanent files. For the VAX and many IBM-compatible PCs, no additional action is needed.

Conversely, if the program was terminated because of errors; and the data, History, and Plot files are not desired, the computers with local and permanent files require no additional action. The applicable files must be "deleted" from the computers which have only permanent files. It is also emphasized that the History and Plot files are opened as FORTRAN Scratch files when they are not requested for retention. This causes the creation of two files (usually started with "FOR" or "ZZ" and followed by a series of characters) when an abnormal shutdown of the program occurs; they should be deleted, also.

A second concern should be ensuring that an adequate number of backup copies is available, without burdening the system with files that are no longer needed. The user must determine at what point

the files are no longer to be kept. Obviously, if the data file(s) is updated daily and the projected testing span is over a year, it would waste the computer storage area if all files were retained. Some previous files should be retained in order to have the ability to recreate the data base from a certain point. That point must be determined by the user on a per analysis basis.

13.3 FORMAT OF THE OPTIONAL PLOT FILE

The optional SMERFS Plot file is designed to be easily input to a separate graphics program to produce high-quality plots of the data. Each selected set of data contains a fixed amount of information. For easier comprehension of this description, refer to Appendixes C and D for CPU TBF and interval data analysis examples, respectively.

The first line contains the 40-character title for the data (as entered in Chapter 12, step g), the number of data points, and the units of measurement. The third field is left blank for interval data. The format of this line is:

(1X,A40,5X,I5,3X,A7)

The next line contains the labels for the axes. The "FAILURE NUMBER" and "WC EXPENDITURE" labels are used for WC TBF data analysis. The "CPU EXPENDITURE" label replaces the Y-axis label when CPU TBF data analysis is done. The "INTERVAL NUMBER", "FAULT COUNT", and "TESTING LENGTH" labels are used for interval data analysis. The format of this line is:

(1X,A15,5X,A15,5X,A15)

The next two lines contain the results from a Goodness-of-Fit analysis. For the TBF data analysis, the lines are set to contain the Kolmogorov distance and the determined adequacy of the model fit. The formats of these lines are either:

(' THE CALCULATED KOLMOGOROV DISTANCE IS',E15.8)
(' THE VALUE MAY PROVIDE AN ADEQUATE FIT AT THE 0.05 LEVEL')

or

(' THE CALCULATED KOLMOGOROV DISTANCE IS',E15.8)
(' THE VALUE MAY NOT PROVIDE AN ADEQUATE FIT AT THE 0.05 LEVEL')

depending on the significance of the distance at the 0.05 level.

For the interval data analysis, the lines are set to an error message (followed by a blank line) if the degrees-of-freedom is computed to be less than one (using a cell combination frequency of five). The format of the error message line is:

(' CHI-SQUARE STATISTIC NOT AVAILABLE')

If the error was not encountered, then the chi-square statistic and the degrees-of-freedom are output. The format of this line is:

(' CHI-SQUARE STATISTIC IS',E15.8,' WITH,I6,' DEGREES-OF-FREEDOM')

The next line (for the TBF data analysis) is set to indicate that the cell combination frequency (5) could not be achieved for the last cell; this line shows the largest achieved value for the last cell. The format of this line is:

(' THE GREATEST VALUE FOR THE LAST CELL WAS',E15.8)

If the cell combination frequency was achieved, the line is left blank.

The remaining lines for this set of data contain the original data, the smoothed original data, the predicted data, the residual data, and the smoothed residual data. The five "blocks" of data are prefixed with an appropriate title line from the formats:

(' VALUES FOR RAW DATA PLOT')
(' VALUES FOR SMOOTHED RAW DATA PLOT')
(' VALUES FOR PREDICTED DATA PLOT')
(' VALUES FOR RESIDUAL DATA PLOT')
(' VALUES FOR SMOOTHED RESIDUAL DATA PLOT')

After the first title, either the raw TBF data or the interval fault counts and testing lengths are listed (one failure or interval per line). The format of the lines is (1X,E15.8) or (1X,2E15.8), respectively. The other four sets of data are all listed (one per line) with a format of (1X,E15.8).

The only deviation from the prior description of the five blocks occurs when the sample size is less than or equal to six. Under that condition, the second and fifth titles are replaced with:

(' *** SAMPLE SIZE TOO SMALL TO SMOOTH ***')

and no data values are listed under those titles.

The next set of data (if available) begins with a new 40-character title and sample size.

CHAPTER 14

REFERENCES

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3. Musa, John; Ianmino, A.; and Okumoto, K., <u>Software Reliability Measurement, Prediction, Application</u>, McGraw Hill, 1987.

4. Yamada, S.; Ohba, M.; and Osaki, S., "S-Shaped Reliability Growth Modeling for Software Error Detection," <u>IEEE Transactions on Reliability</u>, Vol. R-32, Dec 1983.

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6. <u>Recommended Practice, Software Reliability</u>, ANSI/AIAA R-013-1992, 23 Feb 1993.

7. Velleman, Paul F. and Hoaglin, David C., <u>Applications, Basics, and Computing of Exploratory Data Analysis</u>, Boston: Duxbury Press, 1981.

8. Mann, Nancy R.; Schafer, Ray E.; and Singpurwalla, Nozer D., <u>Methods for Statistical Analysis of Reliability and Life Data</u>, Wiley Series in Probability and Mathematical Statistics, New York: John Wiley & Sons, 1974.

9. Schneidewind, Norm, "Optimal Selection of Failure Data for Predicting Failure Counts," <u>Proceedings of the 1993 Complex Systems Engineering Synthesis and Assessment Technology Workshop (CSESAW '93)</u>, NSWCDD/MP-93/172, Jul 1993, NSWCDD, White Oak Det., Silver Spring, MD, pp. 141-157.

APPENDIX A

SAMPLE EXECUTION TIME ANALYSIS

HISTORY FILE

NSWCDD TR 84-373

```
SSSSSSS   M     M   EEEEEE   RRRRRR   FFFFFF   SSSSSSS
S         M M M M   E        R    R   F        S
SSSSSSS   M  M  M   EEEE     RRRRRR   FFFF     SSSSSSS
      S   M     M   E        R   R    F               S
SSSSSSS   M     M   EEEEEE   R    R   F        SSSSSSS
```

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Once activated, the program responds with a banner (including the revision number and the date of release).

ENTER OUTPUT FILE NAME FOR THE HISTORY FILE; ZERO IF THE FILE IS NOT DESIRED, OR ONE FOR DETAILS ON THE FILE.

THE HISTORY FILE IS A COPY OF THE ENTIRE INTERACTIVE SESSION. IT CAN BE USED FOR LATER ANALYSIS AND/OR DOCUMENTATION.

c:\cpu.out

The creation of the History file is desired for this execution; it was used to generate this appendix.

ENTER OUTPUT FILE NAME FOR THE PLOT FILE; ZERO IF THE FILE IS NOT DESIRED, OR ONE FOR DETAILS ON THE FILE.

THE PLOT FILE CONTAINS SELECTED DATA AND LABELS TO ALLOW A USER-SUPPLIED GRAPHICS PROGRAM TO GENERATE HIGH-QUALITY PLOTS. SINCE A CHARACTER PLOTTER IS IMPLEMENTED WITHIN THE SMERFS PROGRAM (TO ENSURE MACHINE PORTABILITY OF THE PACKAGE), THE USE OF THIS OPTION IS HIGHLY RECOMMENDED.

0

The creation of the Plot file is not desired for this execution.

ENTER DESIRED DATA TYPE, OR ZERO FOR A LIST.
0
THE AVAILABLE DATA TYPES ARE:
1 WALL CLOCK (WC) TIME-BETWEEN-FAILURES (TBF)
2 CENTRAL PROCESSING UNITS (CPU) TBF
3 WC TBF AND CPU TBF
4 INTERVAL FAULT COUNTS AND TESTING LENGTHS
ENTER DESIRED DATA TYPE.
2

CPU TBF data are to be analyzed in this execution. Had the user known which of the four options was desired (i.e., option two), the selection could have been entered after the first prompt.

ENTER ONE FOR A STANDARD SMERFS FILE INPUT; ELSE ZERO.
0

A previously generated SMERFS file is not available for this data analysis.

The input of a standard ASCII data file is selected. This is a new feature of the SMERFS3 program (refer to Paragraph 3.2.1).

The (path and) name of the file to be entered is prompted. Additionally, since the ASCII input option was selected, the program also prompts for the units by which the data were measured and for the failure status of the final entry.

A listing of the current data is then requested.

```
ENTER INPUT OPTION, OR ZERO FOR A LIST.
     0
THE AVAILABLE INPUT OPTIONS ARE:
1 ASCII FILE INPUT
2 KEYBOARD INPUT
3 LIST THE CURRENT DATA
4 RETURN TO THE MAIN PROGRAM
ENTER INPUT OPTION.
     1

ENTER INPUT FILE NAME FOR CPU TBF  DATA.
d:\smerfs\smerfs5\cpu2.dat

THE AVAILABLE UNITS FOR TBF DATA PROCESSING ARE:
1 SECONDS   3 HOURS   5 WEEKS    7 YEARS
2 MINUTES   4 DAYS    6 MONTHS
ENTER CODE NUMBER FOR THE CPU TBF  DATA.
     3

THE INPUT OF  29 CPU TBF  ELEMENTS WAS PERFORMED.
THE CPU TBF  STORAGE SPACE NOW CONTAINS  29 ELEMENTS.

ENTER ONE IF A FAILURE HAPPENED AT THE END OF THE FINAL ENTRY,
OR ZERO IF A FAILURE HAD NOT HAPPENED.
     1

ENTER INPUT OPTION, OR ZERO FOR A LIST.
     3

FAILURE    TIME-BETWEEN
NUMBER       HOURS
=======    ============
   1       .26000000E+02
   2       .10000000E+01
   3       .30000000E+01
   4       .61000000E+01
   5       .12700000E+02
   6       .15800000E+02
   7       .20700000E+02
   8       .25100000E+02
   9       .23400000E+02
  10       .30200000E+02
  11       .28100000E+02
  12       .36000000E+02
  13       .45000000E+02
```

```
14    .52000000E+02
15    .71000000E+02
16    .90000000E+02
17    .10000000E+03
18    .88000000E+02
19    .11000000E+03
20    .10500000E+03
21    .12000000E+03
22    .13500000E+03
23    .15500000E+03
24    .18500000E+03
25    .21000000E+03
26    .22000000E+03
27    .25500000E+03
28    .28500000E+03
29    .26500000E+03
```

ENTER INPUT OPTION, OR ZERO FOR A LIST.
0

THE AVAILABLE INPUT OPTIONS ARE:
1 ASCII FILE INPUT
2 KEYBOARD INPUT
3 LIST THE CURRENT DATA
4 RETURN TO THE MAIN PROGRAM
ENTER INPUT OPTION.
4

Data input is complete; request return to the Main Module Menu.

ENTER ONE FOR THE PROGRAM TO MAKE NEW DATA FILES; ELSE ZERO. THE RESPONSE WILL BE USED THROUGHOUT THE EXECUTION. A ZERO WILL ALSO VOID THE DATA RESTORE OPTION IN DATA TRANSFORMATIONS.
0

A new data file of these data is not to be generated (refer to Chapter 2).

ENTER MAIN MODULE OPTION, OR ZERO FOR A LIST.
0

THE AVAILABLE MAIN MODULE OPTIONS ARE:
1 DATA INPUT   6 PLOT(S) OF THE RAW DATA
2 DATA EDIT   7 MODEL APPLICABILITY ANALYSES
3 UNIT CONVERSIONS   8 EXECUTIONS OF THE MODELS
4 DATA TRANSFORMATIONS   9 STOP EXECUTION OF SMERFS
5 DATA STATISTICS
ENTER MAIN MODULE OPTION.
5

Generate summary statistics of the CPU TBF data.

The generated statistics are explained in Chapter 7.

```
        CPU TIME-BETWEEN-FAILURES
        RECORDED IN HOURS
        WITH TOTAL TESTING TIME OF    .27191000E+04
        AND TIME OF LAST FAILURE OF   .27191000E+04
        ***************************************
        *                                     *
MEDIAN OF THE DATA        *         .71000000E+02        *
LOWER & UPPER HINGES      *  .25100000E+02   .13500000E+03  *
MINIMUM AND MAXIMUM       *  .10000000E+01   .28500000E+03  *
NUMBER OF ENTRIES         *              29               *
AVERAGE OF THE DATA       *         .93762069E+02        *
STD. DEV. & VARIANCE      *  .86474275E+02   .74778203E+04  *
SKEWNESS & KURTOSIS       *  .86221967E+00  -.46714675E+00  *
        *                                     *
        ***************************************

ENTER MAIN MODULE OPTION, OR ZERO FOR A LIST.
 6
ENTER A PLOT TITLE (UP TO 30 CHARACTERS).
CPU Data
ENTER ONE TO SMOOTH THE CPU DATA; ELSE ZERO.
 0
```

Generate a plot of the "raw" data.

Notice the increasing reliability trend.

CPU Data

```
ENTER MAIN MODULE OPTION, OR ZERO FOR A LIST.
0
THE AVAILABLE MAIN MODULE OPTIONS ARE:
1 DATA INPUT           6 PLOT(S) OF THE RAW DATA
2 DATA EDIT            7 MODEL APPLICABILITY ANALYSES
3 UNIT CONVERSIONS     8 EXECUTIONS OF THE MODELS
4 DATA TRANSFORMATIONS 9 STOP EXECUTION OF SMERFS
5 DATA STATISTICS
ENTER MAIN MODULE OPTION.
7
```

Perform the preliminary analyses for model applicability.

```
THE ANALYSIS OF THE DATA SET OF SIZE  29 WILL (BY DEFAULT) OCCUR
BETWEEN ELEMENTS  14 AND  28. ENTER ONE TO USE A DIFFERENT RANGE
OR ZERO TO USE THIS RANGE OF  15 ELEMENTS.
0
```

The default range is desired (refer to Section 9.2).

```
ENTER MODEL APPLICABILITY ANALYSIS OPTION, OR ZERO FOR A LIST.
0
THE AVAILABLE MODEL APPLICABILITY ANALYSIS OPTIONS ARE:
1 THE MODEL ACCURACY STATISTIC
2 THE MODEL ACCURACY STATISTIC AND SCATTER PLOT
3 THE MODEL BIAS STATISTIC AND U-PLOT
4 THE MODEL BIAS STATISTIC, U-PLOT, AND SCATTER PLOT
5 THE MODEL NOISE STATISTIC
6 THE MODEL TREND STATISTIC AND Y-PLOT
7 FULL ANALYSIS WITH SUMMARY REPORT ONLY PRINTOUT
8 RETURN TO THE MAIN PROGRAM
ENTER MODEL APPLICABILITY ANALYSIS OPTION.
7
```

Perform a full analysis of Accuracy, Bias, Noise, and Trend Analyses (refer to Section 9.3).

```
ENTER ONE TO SELECT THE MODELS, OR ZERO TO RUN ALL SEVEN.
0
```

All seven models are to be executed.

```
CURRENTLY WORKING ON THE MODEL ACCURACY ANALYSIS.

CURRENTLY WORKING ON THE MODEL BIAS ANALYSIS.

CURRENTLY WORKING ON THE MODEL NOISE ANALYSIS.

CURRENTLY WORKING ON THE MODEL TREND ANALYSIS.
```

All models for all iterations converged successfully (as indicated by the lack of any error messages).

SMERFS then scripts the applicability summary table. It can be seen that the different criteria selected different models; however, there is little variation between the different models (under some criteria). It can further be seen that (although ranked differently) the Musa (Basic) Execution Time model and the Non-homogeneous Poisson model resulted in the same values for all four analyses. The Geometric model will be used in the subsequent analyses.

Obtain additional plots for the Accuracy analysis, using the same iteration range.

```
THE FOLLOWING TABLE SUMMARIZES THE PERFORMED MODEL APPLICABILITY
ANALYSIS.  ZEROS UNDER THE VALUES PORTION INDICATE THE MODEL WAS
EITHER NOT RUN OR FAILED PRIOR TO COMPLETION.  THE INTEGER NUMBER
TO THE RIGHT OF THE VALUE REFLECTS THE RANKING.  THE VALUE TO THE
FAR RIGHT REPRESENTS THE AVERAGE RANKING OF EACH MODEL.

MODEL   ACCURACY/RANK    BIAS/RANK      NOISE/RANK     TREND/RANK    AVG
=====   =============   ============   ============   ============   ===
GEO     .89949E+02 1    .52077E+00 3   .21034E+01 3   .14407E+00 4   2.8
JAM     .99356E+02 7    .56149E+00 5   .38239E+01 7   .27195E+00 7   6.5
LAV-L   .93504E+02 4    .78694E+00 7   .14423E+01 1   .83464E-01 1   3.3
LAV-Q   .90122E+02 2    .64266E+00 6   .15910E+01 2   .97970E-01 2   3.0
MUS-B   .94902E+02 6    .34555E+00 1   .31430E+01 6   .19684E+00 6   4.8
MUS-L   .90914E+02 3    .55599E+00 4   .21526E+01 4   .14271E+00 3   3.5
NPT     .94902E+02 5    .34555E+00 2   .31430E+01 5   .19684E+00 5   4.3


ENTER MAIN MODULE OPTION, OR ZERO FOR A LIST.
7

THE ANALYSIS OF THE DATA SET OF SIZE  29 WILL (BY DEFAULT) OCCUR
BETWEEN ELEMENTS  14 AND  28.  ENTER ONE TO USE A DIFFERENT RANGE
OR ZERO TO USE THIS RANGE OF  15 ELEMENTS.
0

ENTER MODEL APPLICABILITY ANALYSIS OPTION, OR ZERO FOR A LIST.
0

THE AVAILABLE MODEL APPLICABILITY ANALYSIS OPTIONS ARE:
1 THE MODEL ACCURACY STATISTIC
2 THE MODEL ACCURACY STATISTIC AND SCATTER PLOT
3 THE MODEL BIAS STATISTIC AND U-PLOT
4 THE MODEL BIAS STATISTIC, U-PLOT, AND SCATTER PLOT
5 THE MODEL NOISE STATISTIC
6 THE MODEL TREND STATISTIC AND Y-PLOT
7 FULL ANALYSIS WITH SUMMARY REPORT ONLY PRINTOUT
8 RETURN TO THE MAIN PROGRAM
ENTER MODEL APPLICABILITY ANALYSIS OPTION.
2

ENTER ONE TO SELECT THE MODELS, OR ZERO TO RUN ALL SEVEN.
0
```

An Accuracy statistic and a line plot are provided for each model selected.

THE FOLLOWING WERE DETERMINED BASED ON 15 POINTS
GEOMETRIC   STATISTIC IS   .89949330E+02

.70000000E+01 I

.50000000E+01 I

```
         0        10        20        30        40        50
I--------+---------+---------+---------+---------+---------+
```
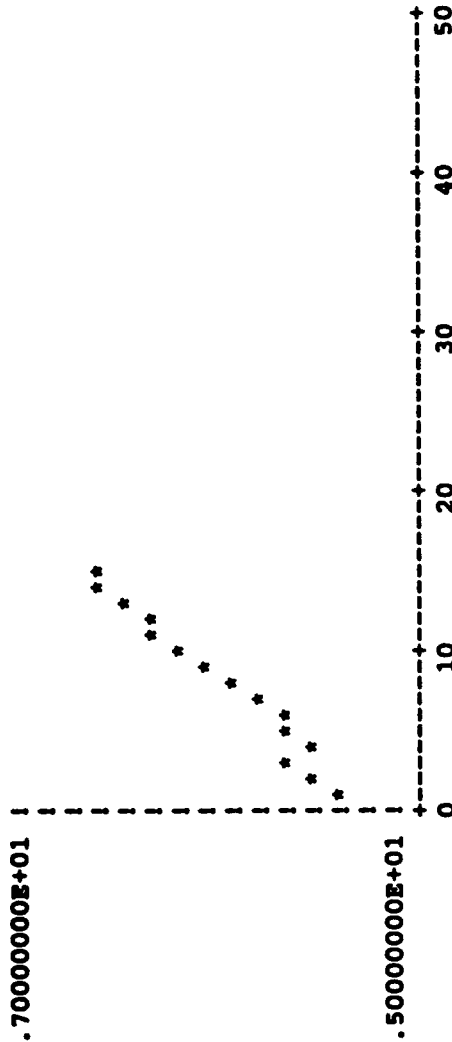
ENTER ONE TO CONTINUE THE PROCESSING.
1

JELINSKI/MORANDA   STATISTIC IS   .99356004E+02

.80000000E+01

.50000000E+01

```
         0        10        20        30        40        50
I--------+---------+---------+---------+---------+---------+
```

ENTER ONE TO CONTINUE THE PROCESSING.
1

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LITTLEWOOD AND VERRALL-LIN STATISTIC IS   .93503723E+02
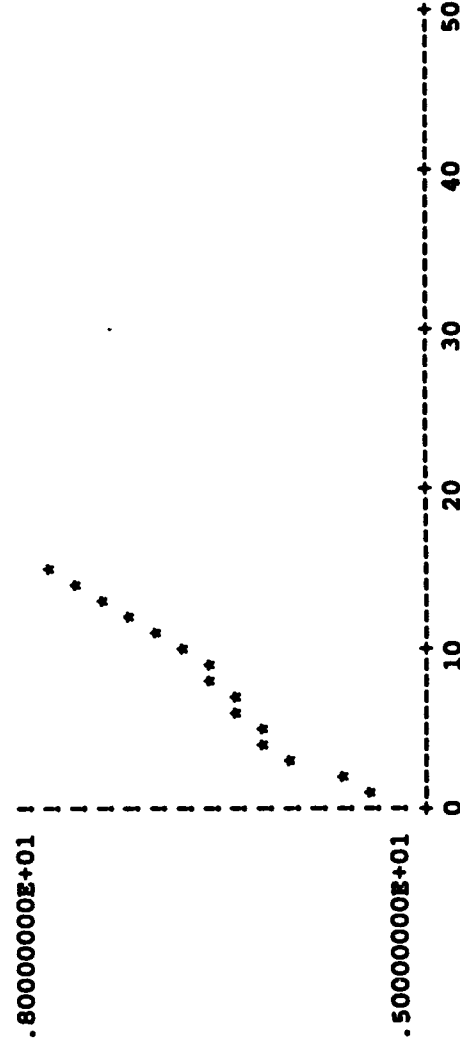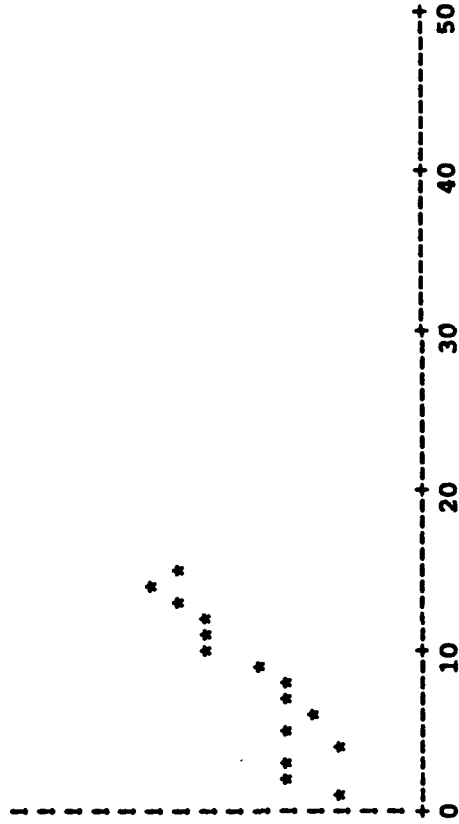
ENTER ONE TO CONTINUE THE PROCESSING.
1

LITTLEWOOD AND VERRALL-QUAD STATISTIC IS   .90122184E+02
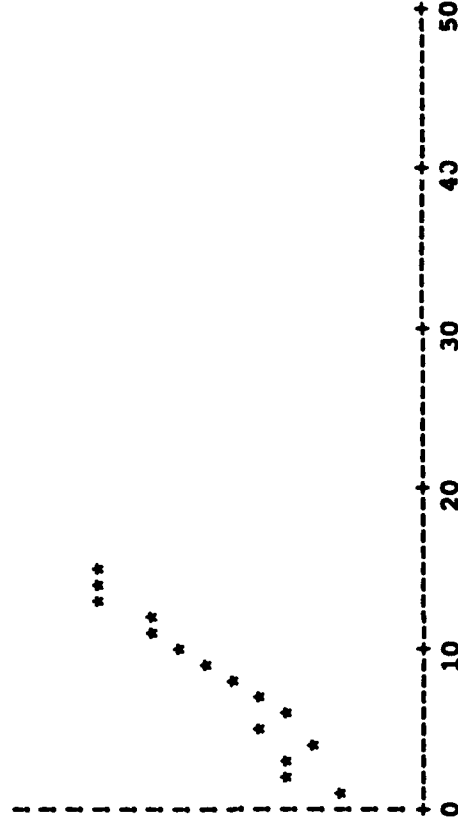
ENTER ONE TO CONTINUE THE PROCESSING.
1

MUSA BASIC EXECUTION   STATISTIC IS   .94901753E+02

.80000000E+01

.50000000E+01

0   10   20   30   40   50
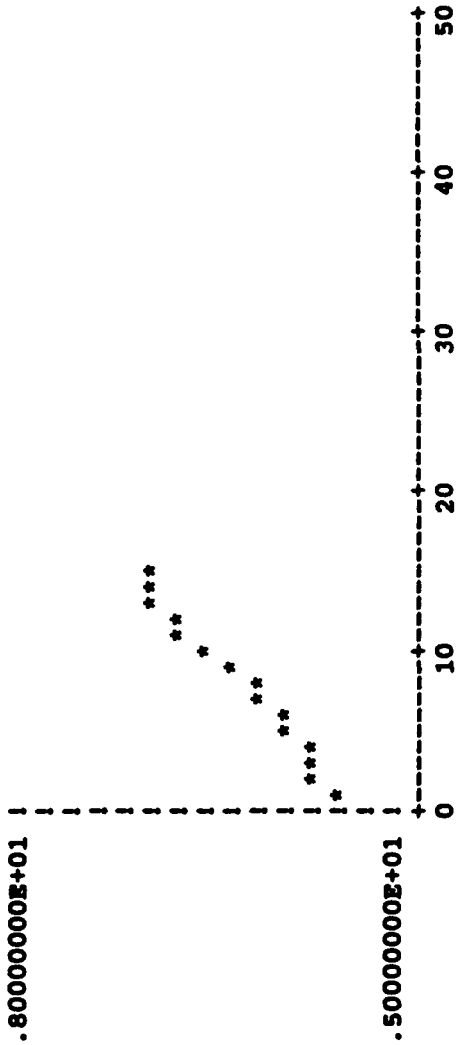
ENTER ONE TO CONTINUE THE PROCESSING.
1

MUSA LOG POISSON EXECUTION STATISTIC IS   .90913778E+02

.70000000E+01

.50000000E+01

0   10   20   30   40   50
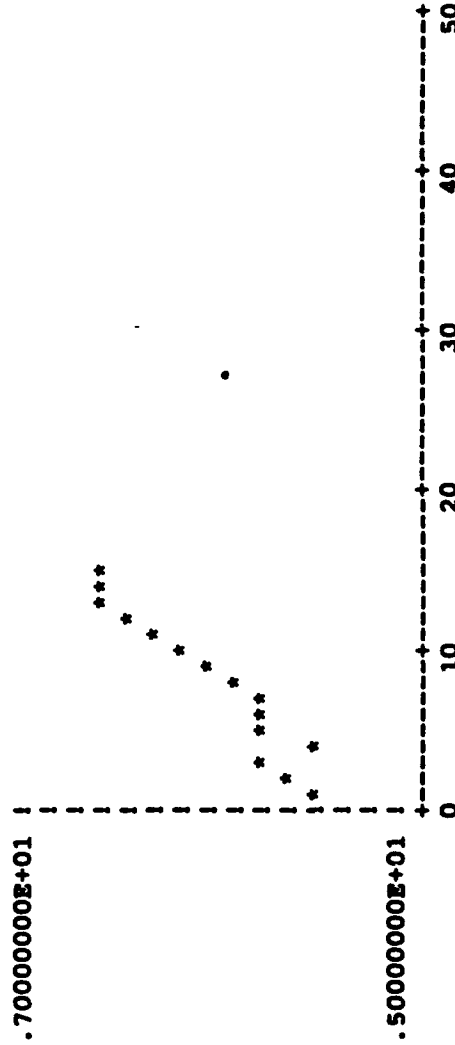
ENTER ONE TO CONTINUE THE PROCESSING.
1

```
NHPP FOR TBF DATA          STATISTIC IS   .94901753E+02

.80000000E+01 !
              !
              !
              !
              !
              !
              !
              !                        ***
              !                       **
              !                      *
              !                     *
              !                   **
              !                  **
              !                ***
              !              ***
              !           *
.50000000E+01 !
              +----+----+----+----+----+
              0   10   20   30   40   50
```
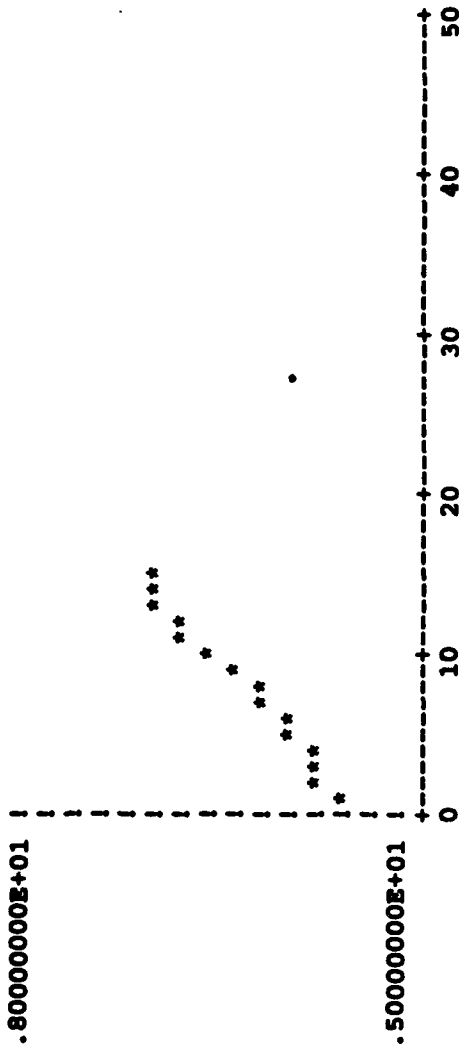
ENTER ONE TO CONTINUE THE PROCESSING.
    1

ENTER MODEL APPLICABILITY ANALYSIS OPTION, OR ZERO FOR A LIST.
    8

THE FOLLOWING TABLE SUMMARIZES THE PERFORMED MODEL APPLICABILITY
ANALYSIS. ZEROS UNDER THE VALUES PORTION INDICATE THE MODEL WAS
EITHER NOT RUN OR FAILED PRIOR TO COMPLETION. THE INTEGER NUMBER
TO THE RIGHT OF THE VALUE REFLECTS THE RANKING. THE VALUE TO THE
FAR RIGHT REPRESENTS THE AVERAGE RANKING OF EACH MODEL.

MODEL	ACCURACY/RANK	BIAS/RANK	NOISE/RANK	TREND/RANK	AVG
=======	===============	===========	============	============	=====
GEO	.89949E+02 1	.00000E+00 0	.00000E+00 0	.00000E+00 0	1.0
JAM	.99356E+02 7	.00000E+00 0	.00000E+00 0	.00000E+00 0	7.0
LAV-L	.93504E+02 4	.00000E+00 0	.00000E+00 0	.00000E+00 0	4.0
LAV-Q	.90122E+02 2	.00000E+00 0	.00000E+00 0	.00000E+00 0	2.0
MUS-B	.94902E+02 6	.00000E+00 0	.00000E+00 0	.00000E+00 0	6.0
MUS-L	.90914E+02 3	.00000E+00 0	.00000E+00 0	.00000E+00 0	3.0
NPT	.94902E+02 5	.00000E+00 0	.00000E+00 0	.00000E+00 0	5.0

Return to the Main Module Menu. Note that the summary table (this time) only reflects the Accuracy, since it was the only analysis performed.

```
ENTER MAIN MODULE OPTION, OR ZERO FOR A LIST.
  0
THE AVAILABLE MAIN MODULE OPTIONS ARE:
 1 DATA INPUT           6 PLOT(S) OF THE RAW DATA
 2 DATA EDIT            7 MODEL APPLICABILITY ANALYSES
 3 UNIT CONVERSIONS     8 EXECUTIONS OF THE MODELS
 4 DATA TRANSFORMATIONS 9 STOP EXECUTION OF SMERFS
 5 DATA STATISTICS
ENTER MAIN MODULE OPTION.
  8
```

Perform executions of the software reliability models.

```
THIS DATA ANALYSIS WILL BE PERFORMED IN UNITS CONSISTENT WITH THE
STORED DATA.  THIS MEANS THAT:

   CPU TBF ESTIMATIONS AND PREDICTIONS WILL BE MADE IN HOURS

ENTER ONE TO CONTINUE WITH THE ANALYSIS;  ELSE ZERO TO RETURN TO
THE MAIN MODULE MENU, SO CONVERSION CAN BE MADE BY MODULE THREE.
  1
```

SMERFS (as all estimations and predictions are made in the units of the resident data) allows the option to abort the analysis if necessary. In this case, continuation is selected.

```
ENTER TIME MODEL OPTION, OR ZERO FOR A LIST.
  0
THE AVAILABLE WALL CLOCK OR CPU TIME MODELS ARE:
 1 THE GEOMETRIC MODEL
 2 THE JELINSKI/MORANDA DE-EUTROPHICATION MODEL
 3 THE LITTLEWOOD AND VERRALL BAYESIAN MODEL
 4 THE MUSA BASIC EXECUTION TIME MODEL
 5 THE MUSA LOG POISSON EXECUTION TIME MODEL
 6 THE NHPP MODEL FOR TIME-BETWEEN-FAILURE OCC.
 7 RETURN TO THE MAIN PROGRAM
ENTER MODEL OPTION.
  1
```

Fit the data using the Geometric model (refer to Paragraph 10.2.1).

```
ENTER ONE FOR GEOMETRIC MODEL DESCRIPTION; ELSE ZERO.
  0
```

The description of the model is not desired.

```
ENTER ONE FOR MAXIMUM LIKELIHOOD METHOD, TWO FOR LEAST SQUARES
METHOD, OR THREE TO TERMINATE MODEL EXECUTION.
  1
```

Maximum Likelihood estimates are to be obtained.

ML MODEL ESTIMATES ARE:
(THE APPROXIMATE 95% CONFIDENCE INTERVALS APPEAR IN PARENTHESES)
PROPORTIONALITY CONSTANT   .87830E+00 (.7466E+00, .1000E+01)
HAZARD RATE PARAMETER   .10889E+00 (.0000E+00, .3418E+00)
INIT. INTENSITY FUNCTION   .12398E+00
CUR. INTENSITY FUNCTION   .27707E-02
MTBNF   .39574E+03 (.1016E+03, .6899E+03)
PURIFICATION LEVEL   .97679E+00 (.9477E+00, .1000E+01)

Convergence is achieved (refer to Paragraph 10.3.1).

THE AVAILABLE FUTURE PREDICTIONS ARE:
1) THE TOTAL MTBNF FOR THE NEXT K FAILURES
2) THE TIME AND NUMBER OF FAILURES TO REACH A DESIRED INTENSITY
   FUNCTION
3) THE NUMBER OF FAILURES EXPECTED IN A SPECIFIED TIME
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.
   1

Explore the first future prediction.

ENTER VALUE OF K, OR ZERO TO END.
   1.
MTBNF EXPECTED   .39574E+03

ENTER VALUE OF K, OR ZERO TO END.
   2.
MTBNF EXPECTED   .84632E+03

Here it is determined that 396 hours would be required to detect the next failure and 846 hours to detect the next two failures.

ENTER VALUE OF K, OR ZERO TO END.
   0.

THE AVAILABLE FUTURE PREDICTIONS ARE:
1) THE TOTAL MTBNF FOR THE NEXT K FAILURES
2) THE TIME AND NUMBER OF FAILURES TO REACH A DESIRED INTENSITY
   FUNCTION
3) THE NUMBER OF FAILURES EXPECTED IN A SPECIFIED TIME
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.
   2

Explore the second future prediction.

ENTER INTENSITY FUNC. (LESS THAN .27707E-02), OR ZERO TO END.
   0.002
ADDITIONAL TESTING TIME   .10717E+04
OF FAILURES EXPECTED   .25117E+01

ENTER INTENSITY FUNC. (LESS THAN .27707E-02), OR ZERO TO END.
   0.

Here it is determined that an additional 1072 hours would be required to increase the intensity function (# of failures/unit time) to 0.002. It is also shown that approximately three failures would be expected in that time.

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THE AVAILABLE FUTURE PREDICTIONS ARE:
1) THE TOTAL MTBNF FOR THE NEXT K FAILURES
2) THE TIME AND NUMBER OF FAILURES TO REACH A DESIRED INTENSITY
   FUNCTION
3) THE NUMBER OF FAILURES EXPECTED IN A SPECIFIED TIME
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.
   3

Explore the third future pre-diction.

ENTER LENGTH OF THE PERIOD, OR ZERO TO END.
   1000.
OF FAILURES EXPECTED   .23669E+01

ENTER LENGTH OF THE PERIOD, OR ZERO TO END.
   0.

Here it is determined that dur-ing an additional 1000 hours, approximately two failures would be expected. (Note, the consistency with the second future prediction.)

THE AVAILABLE FUTURE PREDICTIONS ARE:
1) THE TOTAL MTBNF FOR THE NEXT K FAILURES
2) THE TIME AND NUMBER OF FAILURES TO REACH A DESIRED INTENSITY
   FUNCTION
3) THE NUMBER OF FAILURES EXPECTED IN A SPECIFIED TIME
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.
   0

Terminate the future predictions for the Geometric model.

ENTER ONE FOR MAXIMUM LIKELIHOOD METHOD, TWO FOR LEAST SQUARES
METHOD, OR THREE TO TERMINATE MODEL EXECUTION.
   3

Terminate the Geometric model.

ENTER ONE TO PERFORM AN ANALYSIS OF THE MODEL FIT USING THE PRE-
DICTIONS OF THIS MODEL; ELSE ZERO.
   1

Perform an analysis of how well the Geometric model fits the data being analyzed.

ENTER ANALYSES OPTION, OR ZERO FOR A LIST.
   0
THE AVAILABLE ANALYSES OPTIONS ARE:
1 GOODNESS-OF-FIT TESTS
2 ORIGINAL, PREDICTED, AND RESIDUAL DATA LISTINGS
3 PLOT OF ORIGINAL AND PREDICTED DATA
4 PLOT OF THE RESIDUAL DATA
5 RETURN TO THE MODEL EXECUTION MENU
ENTER ANALYSES OPTION.
   1

Perform the Kolmogorov-Smir-nov Goodness-of-Fit analysis for this execution time data model fit.

The resulting statistic indicates that the model may not provide an adequate fit.

A listing of the current data, predicted data, and the difference between the two is requested.

THE KOLMOGOROV DISTANCE IS .43001343E+00, BASED UPON 29 DATA POINTS. THAT DISTANCE IS SIGNIFICANT AT THE 0.05 LEVEL; THERE-FORE, IT APPEARS THE MODEL MAY NOT PROVIDE AN ADEQUATE FIT.

ENTER ANALYSIS OPTION, OR ZERO FOR A LIST.
2

NUMBER	ORIGINAL DATA	PREDICTED DATA	RESIDUAL DATA
1	.26000000E+02	.91838012E+01	.16816199E+02
2	.10000000E+01	.10456366E+02	-.94563655E+01
3	.30000000E+01	.11905264E+02	-.89052642E+01
4	.61000000E+01	.13554931E+02	-.74549312E+01
5	.12700000E+02	.15433186E+02	-.27331863E+01
6	.15800000E+02	.17571704E+02	-.17717040E+01
7	.20700000E+02	.20006548E+02	.69345198E+00
8	.25100000E+02	.22778779E+02	.23212210E+01
9	.23400000E+02	.25935148E+02	-.25351475E+01
10	.30200000E+02	.29528882E+02	.67111809E+00
11	.28100000E+02	.33620586E+02	-.55205864E+01
12	.36000000E+02	.38279263E+02	-.22792627E+01
13	.45000000E+02	.43583474E+02	.14165259E+01
14	.52000000E+02	.49622670E+02	.23773303E+01
15	.71000000E+02	.56498694E+02	.14501306E+02
16	.90000000E+02	.64327502E+02	.25672498E+02
17	.10000000E+03	.73241119E+02	.26758881E+02
18	.88000000E+02	.83389861E+02	.46101392E+01
19	.11000000E+03	.94944876E+02	.15055124E+02
20	.10500000E+03	.10810102E+03	-.31010247E+01
21	.12000000E+03	.12308017E+03	-.30801711E+01
22	.13500000E+03	.14013492E+03	-.51349207E+01
23	.15500000E+03	.15955288E+03	-.45528818E+01
24	.18500000E+03	.18166152E+03	.33384842E+01
25	.21000000E+03	.20683366E+03	.31663413E+01
26	.22000000E+03	.23549381E+03	-.15493809E+02
27	.25500000E+03	.26812529E+03	-.13125288E+02
28	.28500000E+03	.30527839E+03	-.20278386E+02
29	.26500000E+03	.34757965E+03	-.82579647E+02

Generate a plot of the "raw" data along with those predicted by the model.

Notice that the model seems to predict "low" in the middle and "high" at the end.

ENTER ANALYSIS OPTION, OR ZERO FOR A LIST.
3
ENTER A PLOT TITLE (UP TO 30 CHARACTERS).
Original & Predicted CPU data

Original & Predicted CPU data
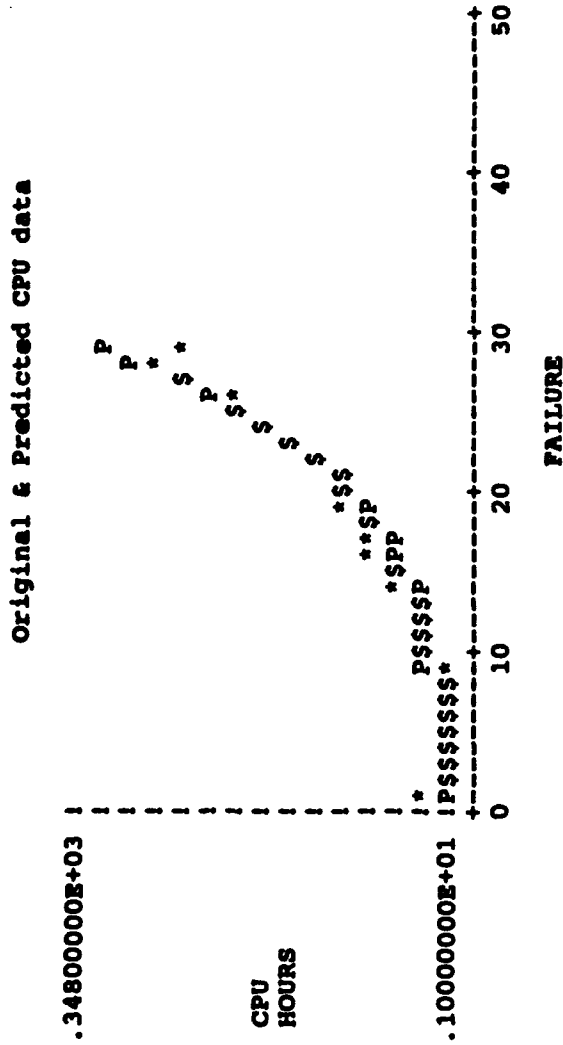
Generate a plot of the residuals (the difference between the raw and the predicted values).

Notice the pattern (possible quadratic term), and the extremely poor match of the final point; this may indicate that the model may not provide an adequate fit.

Terminate the analysis of the model fit.

Terminate the model executions.

ENTER ANALYSES OPTION, OR ZERO FOR A LIST.
4
ENTER A PLOT TITLE (UP TO 30 CHARACTERS).
Residuals for Geometric Model
ENTER ONE TO SMOOTH THE RESIDUALS; ELSE ZERO.
0
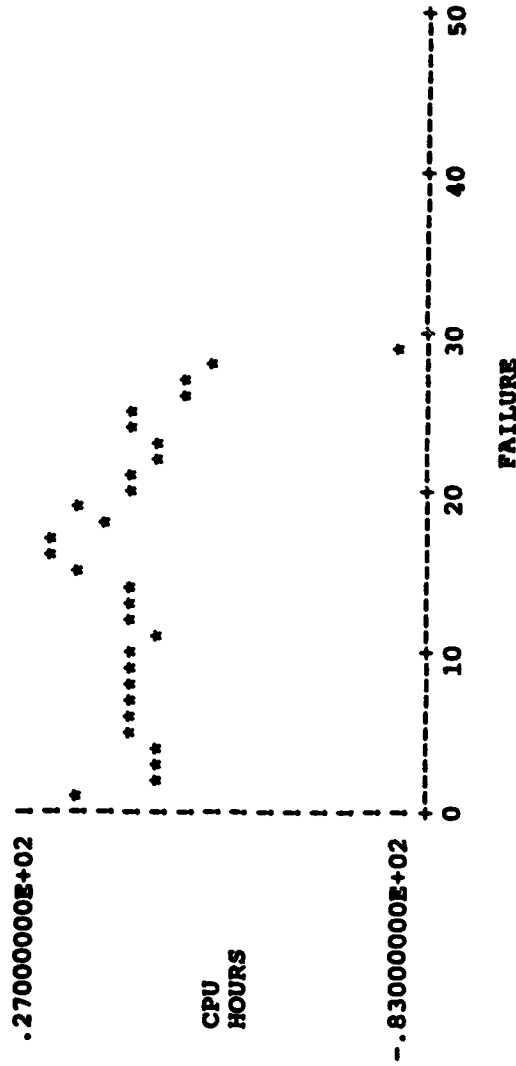
Residuals for Geometric Model

```
.27000000E+02 |
              !        *
              !
              !
              !
              !
              !         ***                    ** *
              !                           *    *
              !                      **   *     ** **
              !          **         *         ***  **
              !      ****** ***   *                    *
              !   ***      *
CPU           !
HOURS         +------+------+------+------+------+------+
              0     10     20     30     40     50
                                            *
-.83000000E+02 !
                              FAILURE
```

ENTER ANALYSES OPTION, OR ZERO FOR A LIST.
5
ENTER TIME MODEL OPTION, OR ZERO FOR A LIST.
0
THE AVAILABLE WALL CLOCK OR CPU TIME MODELS ARE:
1 THE GEOMETRIC MODEL
2 THE JELINSKI/MORANDA DE-EUTROPHICATION MODEL
3 THE LITTLEWOOD AND VERRALL BAYESIAN MODEL
4 THE MUSA BASIC EXECUTION TIME MODEL
5 THE MUSA LOG POISSON EXECUTION TIME MODEL
6 THE NHPP MODEL FOR TIME-BETWEEN-FAILURE OCC.
7 RETURN TO THE MAIN PROGRAM
ENTER MODEL OPTION.
7

Perform a conversion of the measurement units to illustrate this feature.

Convert the TBF data from hours to days.

A listing of the converted data is not desired.

Repeat the software reliability analysis (just completed) using the converted time measurement.

```
ENTER MAIN MODULE OPTION, OR ZERO FOR A LIST.
0

THE AVAILABLE MAIN MODULE OPTIONS ARE:
1 DATA INPUT            6 PLOT(S) OF THE RAW DATA
2 DATA EDIT             7 MODEL APPLICABILITY ANALYSES
3 UNIT CONVERSIONS      8 EXECUTIONS OF THE MODELS
4 DATA TRANSFORMATIONS  9 STOP EXECUTION OF SMERFS
5 DATA STATISTICS
ENTER MAIN MODULE OPTION.
3

THE CPU TBF  DATA ARE CURRENTLY STORED IN HOURS  .

THE DATA MAY BE CONVERTED TO THE FOLLOWING UNITS:
  1 SECONDS   3 HOURS   5 WEEKS      7 YEARS
  2 MINUTES   4 DAYS    6 MONTHS
ENTER NEW CODE NUMBER FOR THE DATA.
4

ENTER ONE TO LIST THE CURRENT DATA; ELSE ZERO.
0

ENTER MAIN MODULE OPTION, OR ZERO FOR A LIST.
8

THIS DATA ANALYSIS WILL BE PERFORMED IN UNITS CONSISTENT WITH THE
STORED DATA.  THIS MEANS THAT:

  CPU TBF ESTIMATIONS AND PREDICTIONS WILL BE MADE IN DAYS

ENTER ONE TO CONTINUE WITH THE ANALYSIS;  ELSE ZERO TO RETURN TO
THE MAIN MODULE MENU, SO CONVERSION CAN BE MADE BY MODULE THREE.
1

ENTER TIME MODEL OPTION, OR ZERO FOR A LIST.
1

ENTER ONE FOR GEOMETRIC MODEL DESCRIPTION; ELSE ZERO.
0

ENTER ONE FOR  MAXIMUM LIKELIHOOD METHOD,  TWO FOR LEAST SQUARES
METHOD, OR THREE TO TERMINATE MODEL EXECUTION.
1
```

All time-related reliability measures are now expressed in days rather than hours.

ML MODEL ESTIMATES ARE:
(THE APPROXIMATE 95% CONFIDENCE INTERVALS APPEAR IN PARENTHESES)
PROPORTIONALITY CONSTANT   .87830E+00 (.7466E+00, .1000E+01)
HAZARD RATE PARAMETER   .26133E+01 (.1472E+01, .3754E+01)
INIT. INTENSITY FUNCTION   .29754E+01
CUR. INTENSITY FUNCTION   .66496E-01
MTBNF   .16489E+02 (.4232E+01, .2875E+02)
PURIFICATION LEVEL   .97679E+00 (.9477E+00, .1000E+01)

THE AVAILABLE FUTURE PREDICTIONS ARE:
1) THE TOTAL MTBNF FOR THE NEXT K FAILURES
2) THE TIME AND NUMBER OF FAILURES TO REACH A DESIRED INTENSITY
   FUNCTION
3) THE NUMBER OF FAILURES EXPECTED IN A SPECIFIED TIME
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.
 1

ENTER VALUE OF K, OR ZERO TO END.
 1.
MTBNF EXPECTED   .16489E+02

ENTER VALUE OF K, OR ZERO TO END.
 2.
MTBNF EXPECTED   .35263E+02

ENTER VALUE OF K, OR ZERO TO END.
 0.

THE AVAILABLE FUTURE PREDICTIONS ARE:
1) THE TOTAL MTBNF FOR THE NEXT K FAILURES
2) THE TIME AND NUMBER OF FAILURES TO REACH A DESIRED INTENSITY
   FUNCTION
3) THE NUMBER OF FAILURES EXPECTED IN A SPECIFIED TIME
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.
 2

ENTER INTENSITY FUNC. (LESS THAN .66496E-01), OR ZERO TO END.
 0.01
ADDITIONAL TESTING TIME   .65471E+03
OF FAILURES EXPECTED   .14599E+02

ENTER INTENSITY FUNC. (LESS THAN .66496E-01), OR ZERO TO END.
0.05

ADDITIONAL TESTING TIME   .38233E+02
OF FAILURES EXPECTED   .21971E+01

ENTER INTENSITY FUNC. (LESS THAN .66496E-01), OR ZERO TO END.
0.

THE AVAILABLE FUTURE PREDICTIONS ARE:
1) THE TOTAL MTBNF FOR THE NEXT K FAILURES
2) THE TIME AND NUMBER OF FAILURES TO REACH A DESIRED INTENSITY
   FUNCTION
3) THE NUMBER OF FAILURES EXPECTED IN A SPECIFIED TIME
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.
3

ENTER LENGTH OF THE PERIOD, OR ZERO TO END.
100.

OF FAILURES EXPECTED   .47942E+01

ENTER LENGTH OF THE PERIOD, OR ZERO TO END.
0.

THE AVAILABLE FUTURE PREDICTIONS ARE:
1) THE TOTAL MTBNF FOR THE NEXT K FAILURES
2) THE TIME AND NUMBER OF FAILURES TO REACH A DESIRED INTENSITY
   FUNCTION
3) THE NUMBER OF FAILURES EXPECTED IN A SPECIFIED TIME
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.
0

ENTER ONE FOR MAXIMUM LIKELIHOOD METHOD, TWO FOR LEAST SQUARES
METHOD, OR THREE TO TERMINATE MODEL EXECUTION.
3

ENTER ONE TO PERFORM AN ANALYSIS OF THE MODEL FIT USING THE PRE-
DICTIONS OF THIS MODEL; ELSE ZERO.
1

Notice that the Kolmogorov distance is not affected by changes in the time units.

ENTER ANALYSIS OPTION, OR ZERO FOR A LIST.
1

THE KOLMOGOROV DISTANCE IS .43001343E+00, BASED UPON 29 DATA POINTS. THAT DISTANCE IS SIGNIFICANT AT THE 0.05 LEVEL; THEREFORE, IT APPEARS THE MODEL MAY NOT PROVIDE AN ADEQUATE FIT.

ENTER ANALYSIS OPTION, OR ZERO FOR A LIST.
3

ENTER A PLOT TITLE (UP TO 30 CHARACTERS).
Geometric Model Fit (Days)

```
                    Geometric Model Fit (Days)

.15000000E+02   I
              I
              I
              I
              I
              I
              I
              I
              I                                      P
              I                                   S
              I                                  P *
              I                                 P*
              I                                S*
              I                               S
              I                             S
              I                            S
              I                          *SS
              I                        **$P
              I                      *$PP
              I                    *$PPP
              I                 PSSSSP
              I!            IPSSSSSS*
              I*          IPSSSSSSSS
.00000000E+00 I*
              I-----I-----I-----I-----I-----I
              0    10    20    30    40    50

CPU
DAYS                      FAILURE
```
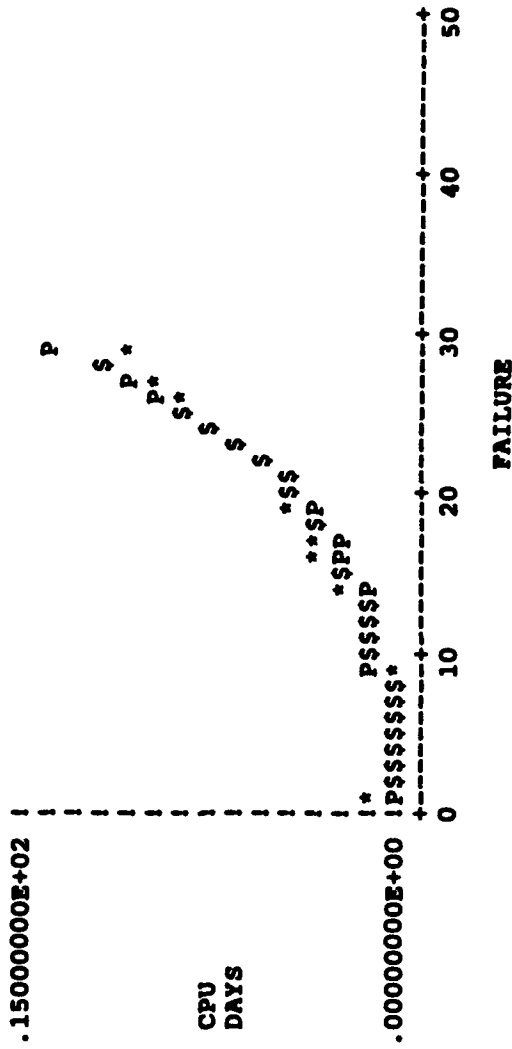
A-22

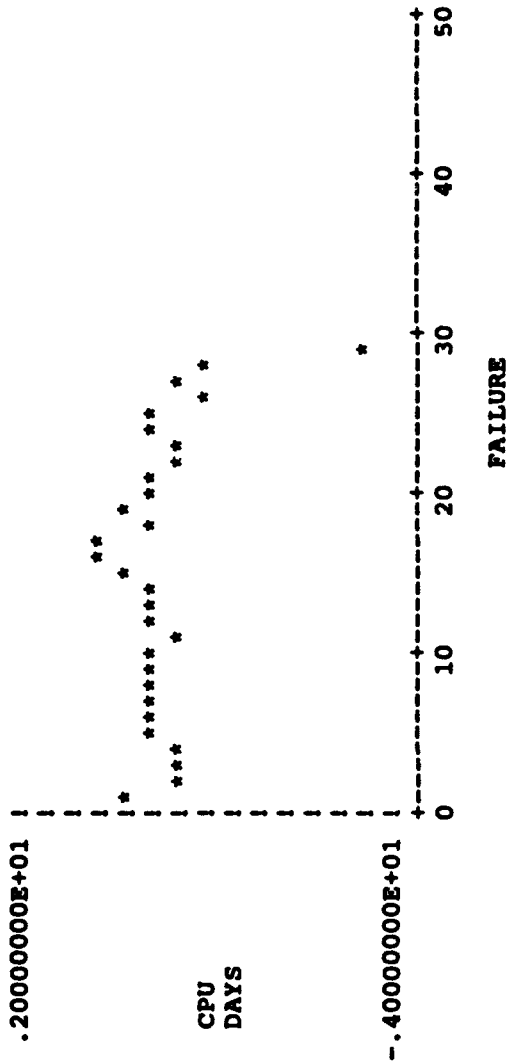ENTER ANALYSES OPTION, OR ZERO FOR A LIST.
    4

ENTER A PLOT TITLE (UP TO 30 CHARACTERS).
Residuals for Geometric (Days)
ENTER ONE TO SMOOTH THE RESIDUALS; ELSE ZERO.
    0

Residuals for Geometric (Days)

```
.20000000E+01 !------------------------------
              !    *
              !    *
              !   ***
              !  ****** ***        *
              !         *
              !       **
              !        *      *
              !           *  * **  **
              !            * ** **          *
              !               * **
              !                 *  *
              !               **   *
CPU           !
DAYS          !
              !
-.40000000E+01 !------+-------+-------+-------+-------+-------+
              0      10      20      30      40      50
                              FAILURE
```

ENTER ANALYSES OPTION, OR ZERO FOR A LIST.
    5

ENTER TIME MODEL OPTION, OR ZERO FOR A LIST.
    0

THE AVAILABLE WALL CLOCK OR CPU TIME MODELS ARE:
    1 THE GEOMETRIC MODEL
    2 THE JELINSKI/MORANDA DE-EUTROPHICATION MODEL
    3 THE LITTLEWOOD AND VERRALL BAYESIAN MODEL
    4 THE MUSA BASIC EXECUTION TIME MODEL
    5 THE MUSA LOG POISSON EXECUTION TIME MODEL
    6 THE NHPP MODEL FOR TIME-BETWEEN-FAILURE OCC.
    7 RETURN TO THE MAIN PROGRAM
ENTER MODEL OPTION.
    7

Terminate the analysis of the model fit.

Terminate the model executions.

Terminate the SMERFS program.

ENTER MAIN MODULE OPTION, OR ZERO FOR A LIST.
    0

THE AVAILABLE MAIN MODULE OPTIONS ARE:
    1 DATA INPUT   6 PLOT(S) OF THE RAW DATA
    2 DATA EDIT   7 MODEL APPLICABILITY ANALYSES
    3 UNIT CONVERSIONS   8 EXECUTIONS OF THE MODELS
    4 DATA TRANSFORMATIONS   9 STOP EXECUTION OF SMERFS
    5 DATA STATISTICS

ENTER MAIN MODULE OPTION.
    9

THE SMERFS EXECUTION HAS ENDED.

APPENDIX B

SAMPLE INTERVAL DATA ANALYSIS

HISTORY FILE

```
SSSSSS  M     M  EEEEEE  RRRRRR  FFFFFF  SSSSSSS
S       M M M M  E       R    R  F       S
SSSSSS  M  M  M  EEEE    RRRRRR  FFFF    SSSSSSS
     S  M     M  E       R   R   F             S
SSSSSS  M     M  EEEEEE  R    R  F       SSSSSSS

       SOFTWARE REVISION NUMBER FIVE (21 SEPTEMBER 1993)
```

Once activated, the program responds with a banner (including the revision number and the date of release).

ENTER OUTPUT FILE NAME FOR THE HISTORY FILE; ZERO IF THE FILE IS NOT DESIRED, OR ONE FOR DETAILS ON THE FILE.

THE HISTORY FILE IS A COPY OF THE ENTIRE INTERACTIVE SESSION. IT CAN BE USED FOR LATER ANALYSIS AND/OR DOCUMENTATION.
c:\count.out

The creation of the History file is desired for this execution; it was used to generate this appendix.

ENTER OUTPUT FILE NAME FOR THE PLOT FILE; ZERO IF THE FILE IS NOT DESIRED, OR ONE FOR DETAILS ON THE FILE.

THE PLOT FILE CONTAINS SELECTED DATA AND LABELS TO ALLOW A USER-SUPPLIED GRAPHICS PROGRAM TO GENERATE HIGH-QUALITY PLOTS. SINCE A CHARACTER PLOTTER IS IMPLEMENTED WITHIN THE SMERFS PROGRAM (TO ENSURE MACHINE PORTABILITY OF THE PACKAGE), THE USE OF THIS OPTION IS HIGHLY RECOMMENDED.
0

The creation of the Plot file is not desired for this execution.

ENTER DESIRED DATA TYPE, OR ZERO FOR A LIST.
0
THE AVAILABLE DATA TYPES ARE:
1 WALL CLOCK (WC) TIME-BETWEEN-FAILURES (TBF)
2 CENTRAL PROCESSING UNITS (CPU) TBF
3 WC TBF AND CPU TBF
4 INTERVAL FAULT COUNTS AND TESTING LENGTHS
ENTER DESIRED DATA TYPE.
4

Interval data are to be analyzed in this execution. Had the user known which of the four options was desired (i.e., option four), the selection could have been entered after the first prompt.

ENTER ONE FOR A STANDARD SMERFS FILE INPUT; ELSE ZERO.
1

A previously generated SMERFS file is available for this data analysis.

```
ENTER INPUT FILE NAME FOR INTERVAL DATA.
d:\smerfs\smerfs5\count2.dat
   THE INPUT OF  15 INTERVAL ELEMENTS WAS PERFORMED.
```

The (path and) name of the file to be entered is prompted. The program responds with the number of periods read.

```
ENTER INPUT OPTION, OR ZERO FOR A LIST.
   0
THE AVAILABLE INPUT OPTIONS ARE:
1 ASCII FILE INPUT
2 KEYBOARD INPUT
3 LIST THE CURRENT DATA
4 RETURN TO THE MAIN PROGRAM
ENTER INPUT OPTION.
   4
```

Data input is complete; request return to the Main Module Menu.

```
ENTER ONE FOR THE PROGRAM TO MAKE NEW DATA FILES; ELSE ZERO. THE
RESPONSE WILL BE USED THROUGHOUT THE EXECUTION. A ZERO WILL ALSO
VOID THE DATA RESTORE OPTION IN DATA TRANSFORMATIONS.
   0
```

A new data file of these data is not to be generated (refer to Chapter 2).

```
ENTER MAIN MODULE OPTION, OR ZERO FOR A LIST.
   0
THE AVAILABLE MAIN MODULE OPTIONS ARE:
1 DATA INPUT              6 PLOT(S) OF THE RAW DATA
2 DATA EDIT               7 MODEL APPLICABILITY ANALYSES
3 UNIT CONVERSIONS        8 EXECUTIONS OF THE MODELS
4 DATA TRANSFORMATIONS    9 STOP EXECUTION OF SMERFS
5 DATA STATISTICS
ENTER MAIN MODULE OPTION.
   5
```

Generate summary statistics of the Interval data.

```
INTERVAL DATA WITH EQUAL LENGTHS
WITH FAULT COUNTS TOTALING TO        317
*********************************************
*                  .20000000E+02            *
* MEDIAN OF THE DATA                         *
* LOWER & UPPER HINGES    .16500000E+02    .25500000E+02 *
* MINIMUM AND MAXIMUM     .13000000E+02    .32000000E+02 *
* NUMBER OF ENTRIES               15        *
* AVERAGE OF THE DATA     .21133333E+02     *
* STD. DEV. & VARIANCE    .58659632E+01    .34409524E+02 *
* SKEWNESS & KURTOSIS     .39387060E+00   -.10212741E+01 *
*********************************************
```

The generated statistics are ex-plained in Chapter 7.

Generate a plot of the "raw" data.

Notice the increasing reliability trend, as reflected in the decreasing number of faults found.

.

The plot of the testing lengths is not desired.

Perform the preliminary analyses for model applicability.

```
ENTER MAIN MODULE OPTION, OR ZERO FOR A LIST.
6
ENTER A COUNT PLOT TITLE (UP TO 30 CHARACTERS).
Count Data
ENTER ONE TO SMOOTH THE COUNT DATA; ELSE ZERO.
0
```


Count Data

```
ENTER ONE FOR ASSOCIATED LENGTH PLOT; ELSE ZERO.
0

ENTER MAIN MODULE OPTION, OR ZERO FOR A LIST.
0
THE AVAILABLE MAIN MODULE OPTIONS ARE:
1 DATA INPUT           6 PLOT(S) OF THE RAW DATA
2 DATA EDIT            7 MODEL APPLICABILITY ANALYSES
3 UNIT CONVERSIONS     8 EXECUTIONS OF THE MODELS
4 DATA TRANSFORMATIONS 9 STOP EXECUTION OF SMERFS
5 DATA STATISTICS
ENTER MAIN MODULE OPTION.
7
```

THE ANALYSIS OF THE DATA SET OF SIZE 15 WILL (BY DEFAULT) OCCUR
BETWEEN ELEMENTS 7 AND 14. ENTER ONE TO USE A DIFFERENT RANGE
OR ZERO TO USE THIS RANGE OF 8 ELEMENTS.
0

The default range is desired (refer to Section 9.2).

ENTER MODEL APPLICABILITY ANALYSIS OPTION, OR ZERO FOR A LIST.
0
THE AVAILABLE MODEL APPLICABILITY ANALYSIS OPTIONS ARE:
1 THE MODEL ACCURACY STATISTIC
2 THE MODEL ACCURACY STATISTIC AND SCATTER PLOT
3 SUMMARY REPORT ONLY PRINTOUT
4 RETURN TO THE MAIN PROGRAM
ENTER MODEL APPLICABILITY ANALYSIS OPTION.
2

Obtain the statistics and plots for the Accuracy (refer to Section 9.3).

ENTER ONE TO SELECT THE MODELS, OR ZERO TO RUN ALL SIX.
0

ENTER ALPHA (THE PROB. OF CORRECTING FAULTS, WITHOUT INSERTING
NEW ONES) FOR THE BROOKS AND MOTLEY MODEL.
0.85

ENTER ALPHA (COUNT(I)**ALPHA) FOR THE GENERALIZED POISSON MODEL.
2.

All six models are to be executed; provide the additional values for the Brooks and Motley model and the Generalized Poisson model.

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An Accuracy statistic and a line plot are provided for each model selected.
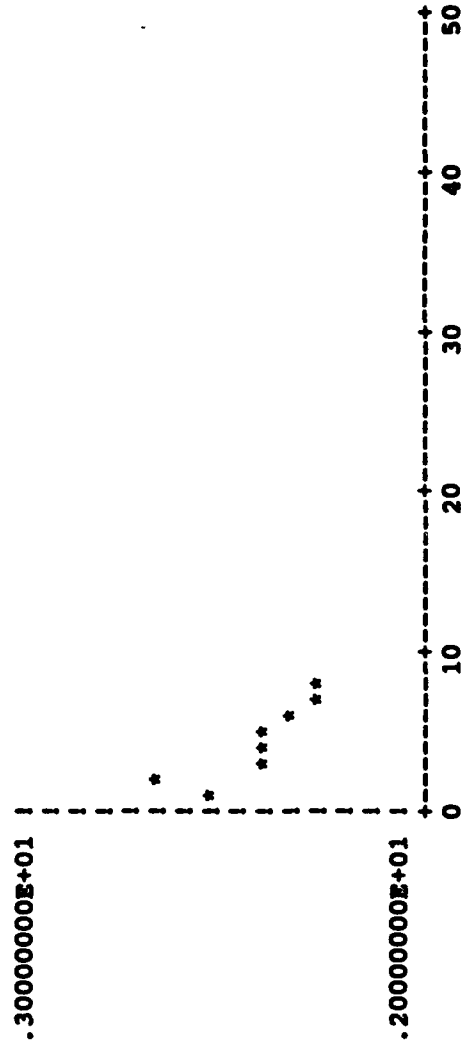
THE FOLLOWING WERE DETERMINED BASED ON   8 POINTS
BROOKS AND MOTLEY-BIN STATISTIC IS   .19096179E+02
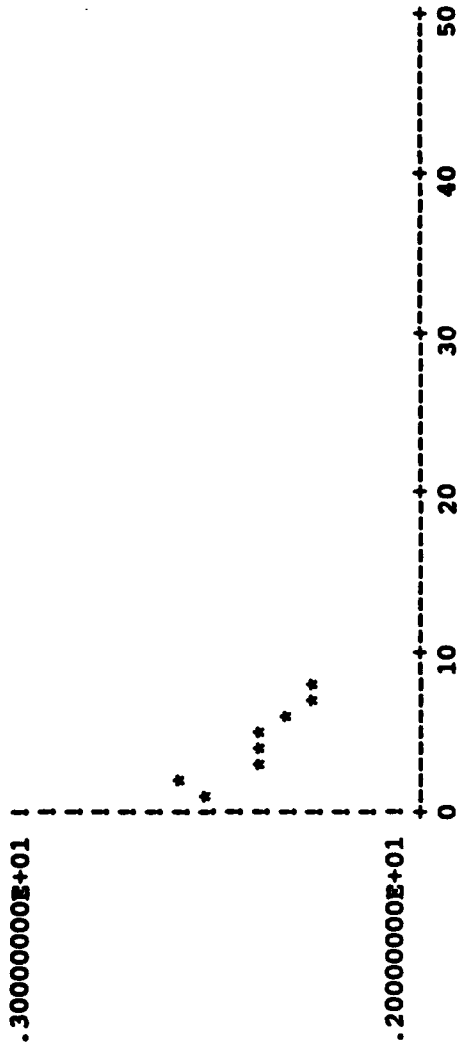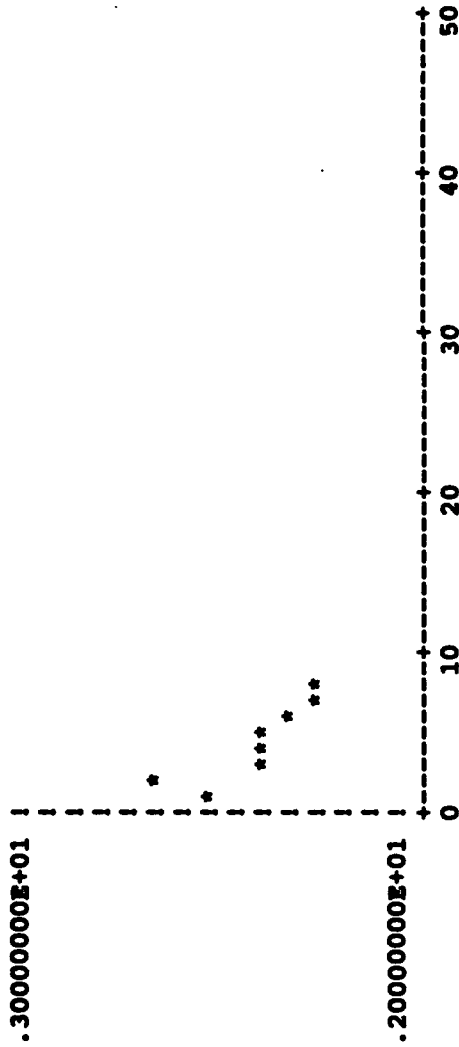

ENTER ONE TO CONTINUE THE PROCESSING.
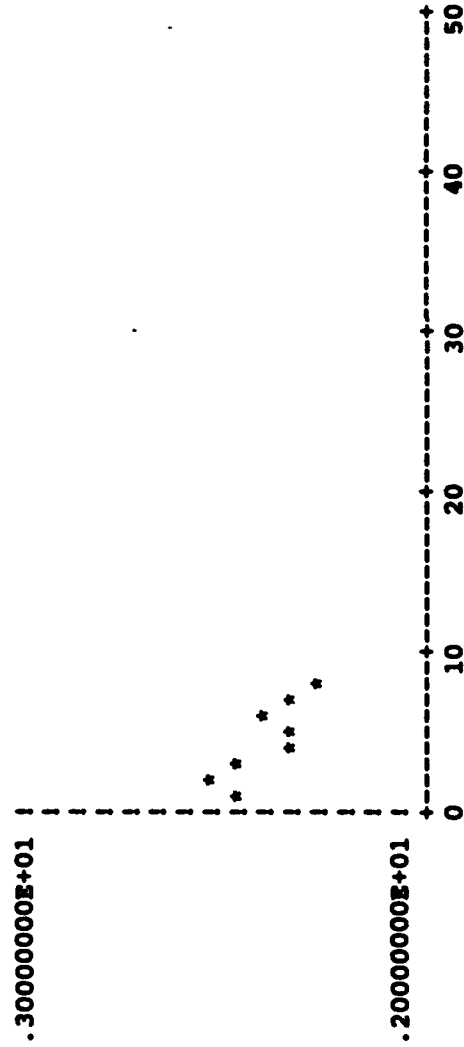1

BROOKS AND MOTLEY-POI STATISTIC IS   .19245845E+02

ENTER ONE TO CONTINUE THE PROCESSING.
1

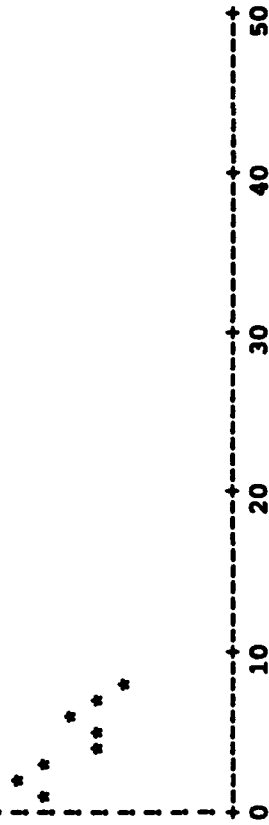GENERALIZED POISSON   STATISTIC IS   .19246036E+02

.30000000E+01

.20000000E+01

ENTER ONE TO CONTINUE THE PROCESSING.
1

NHPP FOR INT. DATA   STATISTIC IS   .18958350E+02

.30000000E+01

.20000000E+01

ENTER ONE TO CONTINUE THE PROCESSING.
1

SCHNEIDEWIND MODEL   STATISTIC IS   .18958350E+02
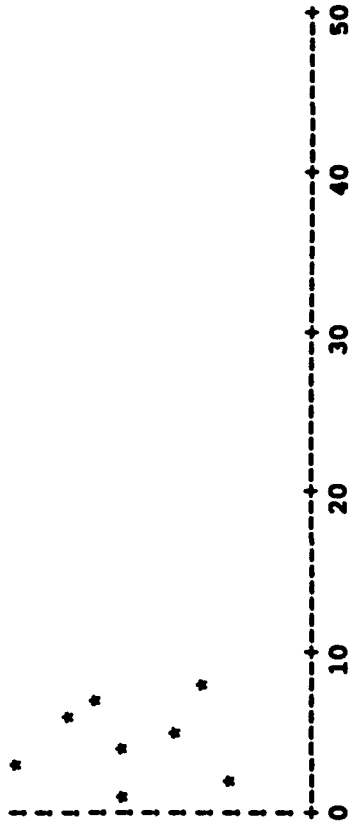
.30000000E+01

.20000000E+01

ENTER ONE TO CONTINUE THE PROCESSING.
1

S-SHAPED REL. GROWTH   STATISTIC IS   .38389759E+02

.70000000E+01

.30000000E+01

ENTER ONE TO CONTINUE THE PROCESSING.
1

ENTER MODEL APPLICABILITY ANALYSIS OPTION, OR ZERO FOR A LIST.
0

THE AVAILABLE MODEL APPLICABILITY ANALYSIS OPTIONS ARE:
1 THE MODEL ACCURACY STATISTIC
2 THE MODEL ACCURACY STATISTIC AND SCATTER PLOT
3 SUMMARY REPORT ONLY PRINTOUT
4 RETURN TO THE MAIN PROGRAM
ENTER MODEL APPLICABILITY ANALYSIS OPTION.
4

Return to the Main Module Menu.

THE FOLLO. NG TABLE SUMMARIZES THE PERFORMED MODEL APPLICABILITY
ANALYSIS. ZEROS UNDER THE VALUES PORTION INDICATE THE MODEL WAS
EITHER NOT RUN OR FAILED PRIOR TO COMPLETION. THE INTEGER NUMBER
TO THE RIGHT OF THE VALUE REFLECTS THE RANKING.

MODEL	ACCURACY/RANK	
=======	========	=====
BAM-B	.19096E+02	3
BAM-P	.19246E+02	4
GPN	.19246E+02	5
NPI	.18958E+02	2
SDW	.18958E+02	1
SSH	.38390E+02	6

SMERFS then scripts the applicability summary table. It can be seen that the Non-homogeneous Poisson model and the Schneidewind model tied for first place; although, there is actually little variation between all the models (with the exclusion of the S-Shaped model, which was largely inferior to the rest of the models for this data set).

ENTER MAIN MODULE OPTION, OR ZERO FOR A LIST.
0

THE AVAILABLE MAIN MODULE OPTIONS ARE:
1 DATA INPUT
2 DATA EDIT
3 UNIT CONVERSIONS
4 DATA TRANSFORMATIONS
5 DATA STATISTICS
6 PLOT(S) OF THE RAW DATA
7 MODEL APPLICABILITY ANALYSES
8 EXECUTIONS OF THE MODELS
9 STOP EXECUTION OF SMERFS
ENTER MAIN MODULE OPTION.
8

Perform executions of the software reliability models.

Fit the data using the Schneidewind model (refer to Paragraph 11.2.4).

The description of the model is not desired; however, the additional description of the three treatment types is requested.

Perform the investigation to determine if an optimum starting point (S) exists for this data set.

```
ENTER COUNT MODEL OPTION, OR ZERO FOR A LIST.
      0
THE AVAILABLE FAULT COUNT MODELS ARE:
1 THE BROOKS AND MOTLEY MODEL
2 THE GENERALIZED POISSON MODEL
3 THE NON-HOMOGENEOUS POISSON MODEL
4 THE SCHNEIDEWIND MODEL
5 THE S-SHAPED RELIABILITY GROWTH MODEL
6 RETURN TO THE MAIN PROGRAM
ENTER MODEL OPTION.
      4

ENTER ONE FOR SCHNEIDEWIND MODEL DESCRIPTION; ELSE ZERO.
      0

ENTER ONE FOR DESCRIPTION OF TREATMENT TYPES; ELSE ZERO.
      1

TREATMENT 1 - UTILIZE ALL FAULT COUNTS FROM EACH OF THE TESTING
              PERIODS.

TREATMENT 2 - IGNORE FAULT COUNTS FROM THE FIRST "S-1" TESTING
              PERIODS AND USE ONLY THE FAULT COUNTS FROM PER-
              IOD "S" THROUGH THE TOTAL NUMBER OF PERIODS.

TREATMENT 3 - USE CUMULATIVE NUMBER OF FAULTS FROM PERIODS ONE
              THROUGH "S-1" AND THE INDIVIDUAL COUNTS FROM PER-
              IOD "S" THROUGH THE TOTAL NUMBER OF PERIODS.

ENTER ONE TO INVESTIGATE FOR THE OPTIMUM S (USING TREATMENT TYPE
NUMBER 2); ELSE ZERO TO CONTINUE WITH THE MODEL EXECUTION.
      1

ENTER RANGE OVER WHICH S SHOULD BE TESTED. NOTE, AN EXECUTION
ON A GIVEN S WHICH FAILED THE CONVERGENCE CRITERIA WILL NOT BE
INCLUDED IN THE FOLLOWING RESULTS TABLE. THE OPTIMUM S FOR EI-
THER MSE-F OR MSE-T IS THE ONE RESULTING IN THE SMALLEST VALUE
FOR YOUR CHOSEN CRITERIA.
      7
      1
```

The resulting statistics are explained in Paragraph 11.3.4.

Since the criteria values are still getting smaller, the investigation is repeated with an increased upper limit (to ensure that the global minimum has been reached).

The tenth attempt failed within the model execution. The WLS and MSE_F both point to eight, and the MSE_T points to nine. It is up to the user to determine which starting point should be used in the actual model execution (refer to Paragraph 11.3.4).

Treatment type 2 estimates are to be obtained. Here the first seven periods will be ignored.

S	BETA	ALPHA	WLS	MSE-F	MSE-T
1	.60472E-01	.32148E+02	.28636E+01	.10415E+01	.23452E-02
2	.62208E-01	.30706E+02	.27732E+01	.13486E+01	.28171E-02
3	.58256E-01	.27972E+02	.22038E+01	.97395E+00	.24824E-02
4	.58634E-01	.26462E+02	.22530E+01	.10238E+01	.25925E-02
5	.60545E-01	.25277E+02	.22685E+01	.10512E+01	.25368E-02
6	.65794E-01	.24566E+02	.20256E+01	.16989E+01	.41299E-02
7	.55755E-01	.21762E+02	.11529E+01	.43111E+00	.13724E-02

ENTER ONE TO INVESTIGATE ANOTHER RANGE FOR S; ELSE ZERO.
1

ENTER RANGE OVER WHICH S SHOULD BE TESTED. NOTE, AN EXECUTION ON A GIVEN S WHICH FAILED THE CONVERGENCE CRITERIA WILL NOT BE INCLUDED IN THE FOLLOWING RESULTS TABLE. THE OPTIMUM S FOR EITHER MSE-F OR MSE-T IS THE ONE RESULTING IN THE SMALLEST VALUE FOR YOUR CHOSEN CRITERIA.
10

S	BETA	ALPHA	WLS	MSE-F	MSE-T
1	.60472E-01	.32148E+02	.28636E+01	.10415E+01	.23452E-02
2	.62208E-01	.30706E+02	.27732E+01	.13486E+01	.28171E-02
3	.58256E-01	.27972E+02	.22038E+01	.97395E+00	.24824E-02
4	.58634E-01	.26462E+02	.22530E+01	.10238E+01	.25925E-02
5	.60545E-01	.25277E+02	.22685E+01	.10512E+01	.25368E-02
6	.65794E-01	.24566E+02	.20256E+01	.16989E+01	.41299E-02
7	.55755E-01	.21762E+02	.11529E+01	.43111E+00	.13724E-02
8	.50645E-01	.20068E+02	.10578E+01	.33243E+00	.13061E-02
9	.46961E-01	.18774E+02	.10886E+01	.43811E+00	.96827E-03

ENTER ONE TO INVESTIGATE ANOTHER RANGE FOR S; ELSE ZERO.
0

ENTER DESIRED MODEL TREATMENT NUMBER, OR FOUR TO TERMINATE MODEL EXECUTION.
2

ENTER ASSOCIATED VALUE OF S (LESS THAN THE NUMBER OF PERIODS).
8

```
TREATMENT 2 MODEL ESTIMATES ARE:
BETA                              .50645E-01
ALPHA                             .20068E+02
TOTAL NUMBER OF FAULTS            .39624E+03
  PLUS THOSE SKIPPED              .18500E+03  IN PERIODS 1 THROUGH 7
# OF FAULTS REMAINING             .79240E+02
WEIGHTED SUMS-OF-SQUARES
  BETWEEN PREDICTED AND
  OBSERVED FAULTS                 .10578E+01
MEAN SQUARE ERROR FOR
  CUMULATIVE FAULTS               .33243E+00
MEAN SQUARE ERROR FOR
  TIME TO NEXT FAILURE            .13061E-02


THE AVAILABLE FUTURE PREDICTIONS ARE:
1) THE NUMBER OF FAULTS EXPECTED IN THE NEXT TESTING PERIOD
2) THE NUMBER OF PERIODS NEEDED TO DISCOVER THE NEXT M FAULTS
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.
  1

ENTER NUMBER OF PERIODS TO EXAMINE, OR ZERO TO END.
  1.
# OF FAULTS EXPECTED        .13049E+02

ENTER NUMBER OF PERIODS TO EXAMINE, OR ZERO TO END.
  0.

THE AVAILABLE FUTURE PREDICTIONS ARE:
1) THE NUMBER OF FAULTS EXPECTED IN THE NEXT TESTING PERIOD
2) THE NUMBER OF PERIODS NEEDED TO DISCOVER THE NEXT M FAULTS
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.
  2

ENTER VALUE OF M (BETWEEN ONE AND  .79240E+02), OR ZERO TO END.
  79.
# OF PERIODS EXPECTED       .70136E+01

ENTER VALUE OF M (BETWEEN ONE AND  .79240E+02), OR ZERO TO END.
  0.
```

Convergence is achieved (refer to Paragraph 11.3.4).

Note: The estimate of the total number of faults in the software is 581 (the sum of 396 and the 185 faults ignored in the first seven periods).

Explore the first future prediction.

Here it is determined that within the next testing period, 13 faults would be expected.

Explore the second future prediction.

Here it is determined that seven periods would be required to detect all remaining faults in the program.

THE AVAILABLE FUTURE PREDICTIONS ARE:
1) THE NUMBER OF FAULTS EXPECTED IN THE NEXT TESTING PERIOD
2) THE NUMBER OF PERIODS NEEDED TO DISCOVER THE NEXT M FAULTS
ENTER PREDICTION OPTION, OR ZERO TO END PREDICTIONS.
0

Terminate the future predictions for the Schneidewind model.

ENTER DESIRED MODEL TREATMENT NUMBER, OR FOUR TO TERMINATE MODEL
EXECUTION.
4

Terminate the Schneidewind model.

ENTER ONE TO PERFORM AN ANALYSIS OF THE MODEL FIT USING THE PRE-
DICTIONS OF THIS MODEL; ELSE ZERO.
1

Perform an analysis of how well the Schneidewind model fits the data being analyzed.

NOTE: THE STARTING INDEX OF THE DATA IS SHIFTED BY   7 UNITS TO
REFLECT TREATMENT TYPE 2

The program shifts the data points to compensate for those omitted from analysis.

ENTER ANALYSES OPTION, OR ZERO FOR A LIST.
0
THE AVAILABLE ANALYSES OPTIONS ARE:
1 GOODNESS-OF-FIT TESTS
2 ORIGINAL, PREDICTED, AND RESIDUAL DATA LISTINGS
3 PLOT OF ORIGINAL AND PREDICTED DATA
4 PLOT OF THE RESIDUAL DATA
5 RETURN TO THE MODEL EXECUTION MENU
ENTER ANALYSES OPTION.
1

Perform the chi-square Goodness-of-Fit analysis for this interval data model fit.

ENTER THE CELL COMBINATION FREQUENCY (THE STANDARD IS FIVE), OR
A MINUS ONE TO INDICATE NO CELL COMBINATIONS.
-1.
THE CHI-SQUARE STATISTIC IS .41109159E+00 WITH   5 DEGREES-
OF-FREEDOM.

Table look-up shows that the model may provide an adequate fit.

ENTER ONE TO TRY ANOTHER COMBINATION FREQUENCY; ELSE ZERO.
0

Generate a plot of the "raw" data along with those predicted by the model.

ENTER ANALYSES OPTION, OR ZERO FOR A LIST.
    0

THE AVAILABLE ANALYSES OPTIONS ARE:
1 GOODNESS-OF-FIT TESTS
2 ORIGINAL, PREDICTED, AND RESIDUAL DATA LISTINGS
3 PLOT OF ORIGINAL AND PREDICTED DATA
4 PLOT OF THE RESIDUAL DATA
5 RETURN TO THE MODEL EXECUTION MENU
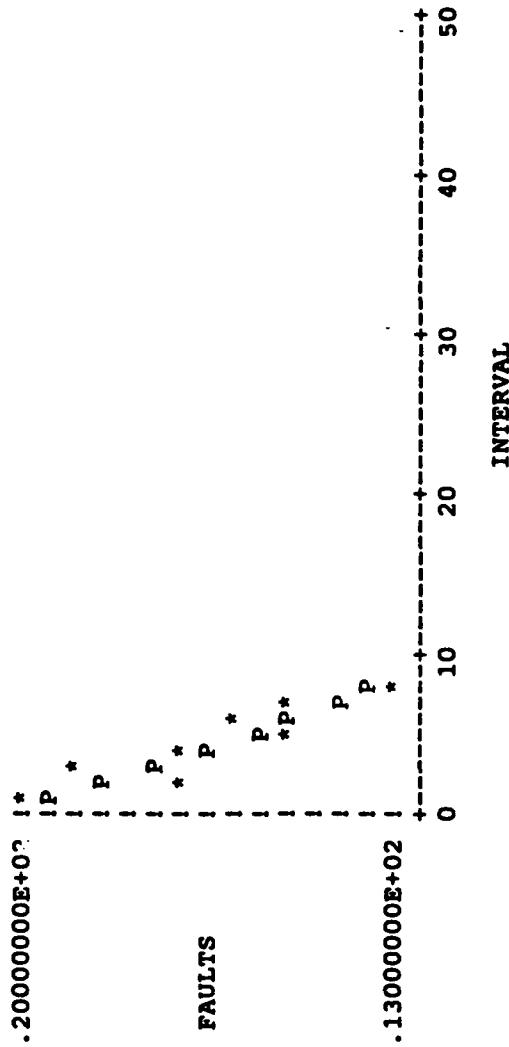ENTER ANALYSES OPTION.
    3

ENTER A PLOT TITLE (UP TO 30 CHARACTERS).
Original and Predicted Data

                Original and Predicted Data

.20000000E+02 !*
             !P
             !   *
             !P
             !   P
             !   * *   P
             !   P
FAULTS   !   *
             !   P
             !   *P*
             !   P
             !   P
             !   *
.13000000E+02 !-----+-----+-----+-----+-----+-----+
             0   10   20   30   40   50
                        INTERVAL

Notice that the first 7 of 15 points are not plotted, since the starting point was set to 8 for this execution. Also notice that the model appears to "track" the real data rather well.

ENTER ANALYSES OPTION, OR ZERO FOR A LIST.
    0

THE AVAILABLE ANALYSES OPTIONS ARE:
1 GOODNESS-OF-FIT TESTS
2 ORIGINAL, PREDICTED, AND RESIDUAL DATA LISTINGS
3 PLOT OF ORIGINAL AND PREDICTED DATA
4 PLOT OF THE RESIDUAL DATA
5 RETURN TO THE MODEL EXECUTION MENU
ENTER ANALYSES OPTION.
    4

Generate a plot of the residuals (the difference between the raw and the predicted values).
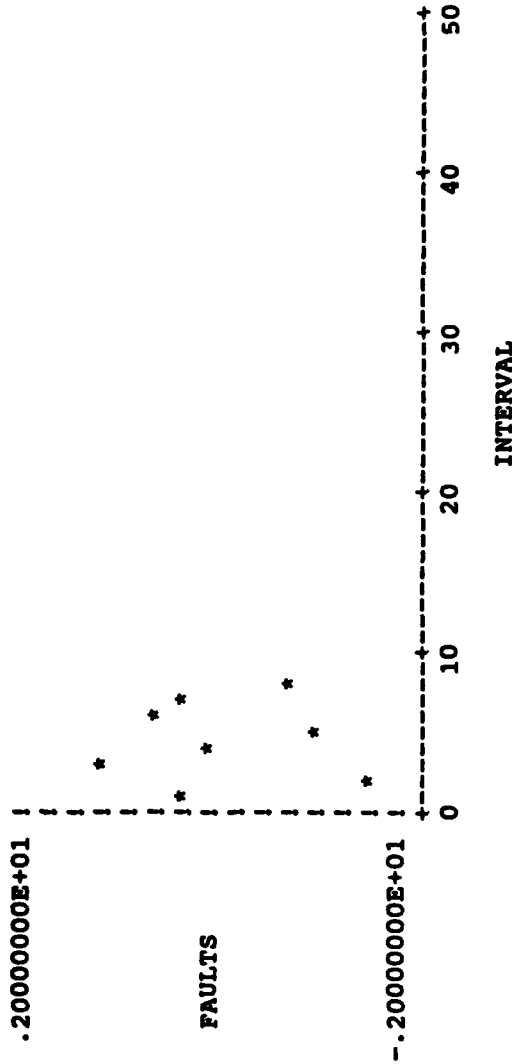
ENTER A PLOT TITLE (UP TO 30 CHARACTERS).
Residual Data Plot for Counts
ENTER ONE TO SMOOTH THE RESIDUALS; ELSE ZERO.
0

Residual Data Plot for Counts

ENTER ANALYSES OPTION, OR ZERO FOR A LIST.
5

Terminate the analysis of the model fit.

ENTER COUNT MODEL OPTION, OR ZERO FOR A LIST.
6

Terminate the model execution.

ENTER MAIN MODULE OPTION, OR ZERO FOR A LIST.
9

Terminate the SMERFS program.

THE SMERFS EXECUTION HAS ENDED.

Notice the randomness of and the smallness in the residuals; this possibly (again) indicates that the model may provide an adequate fit.

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APPENDIX C

SAMPLE EXECUTION TIME ANALYSIS

PLOT FILE

Sample CPU TBF Plot File   17   MINUTES
FAILURE NUMBER   CPU EXPENDITURE
THE CALCULATED KOLMOGOROV DISTANCE IS .40834229E+00
THE MODEL MAY NOT PROVIDE AN ADEQUATE FIT AT THE 0.05 LEVEL
VALUES FOR RAW DATA PLOT
    .10000000E+01
    .40000000E+02
          .
          .
          .
    .60000000E+03
    .90000000E+03
VALUES FOR SMOOTHED RAW DATA PLOT
  -.27500000E+01
    .14000000E+02
          .
          .
          .
    .75000000E+03
    .90000000E+03
VALUES FOR PREDICTED DATA PLOT
    .15094311E+02
    .19899128E+02
          .
          .
          .
    .95306927E+03
    .12564500E+04
VALUES FOR RESIDUAL DATA PLOT
  -.14094311E+02
    .20100872E+02
          .
          .
          .
  -.35306927E+03
  -.35645001E+03
VALUES FOR SMOOTHED RESIDUAL DATA PLOT
  -.13243311E+02
  -.81920603E+01
          .
          .
          .
  -.27774257E+03
  -.35645001E+03

APPENDIX D

SAMPLE INTERVAL DATA ANALYSIS

PLOT FILE

```
Sample Interval Plot File                        30
INTERVAL NUMBER      FAULT COUNT        TESTING LENGTH
CHI-SQUARE STATISTIC IS  .39882601E+02 WITH    21 DEGREES-OF-FREEDOM

VALUES FOR RAW DATA PLOT
   .20000000E+02   .10000000E+01
   .18000000E+02   .10000000E+01
         .              .
         .              .
         .              .
   .00000000E+00   .10000000E+01
   .10000000E+01   .10000000E+01
VALUES FOR SMOOTHED RAW DATA PLOT
   .22000000E+02
   .22000000E+02
         .
         .
         .
   .00000000E+00
   .00000000E+00
VALUES FOR PREDICTED DATA PLOT
   .29821787E+02
   .27064728E+02
         .
         .
         .
   .19719396E+01
   .17896314E+01
VALUES FOR RESIDUAL DATA PLOT
  -.98217869E+01
  -.90647276E+01
         .
         .
         .
  -.19719396E+01
  -.78963144E+00
VALUES FOR SMOOTHED RESIDUAL DATA PLOT
  -.81962454E+01
  -.60029095E+01
         .
         .
         .
  -.13823581E+01
  -.89518715E+00
```

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This is the third in a series of Naval Surface Warfare Center Dahlgren Division (NSWCDD) technical reports concerning software reliability. The first report, A Survey of Software Reliability Modeling and Estimation, NSWC TR 82-171, discusses various approaches advocated for reliability estimation; reviews various models proposed for this estimation process; provides model assumptions, estimates of reliability, and the precision of those estimates; and provides the data required for the models' implementation. Eight software reliability models were selected to form the basis of a library. This library also contains data edit, transformation, general statistics, and Goodness-of-Fit functions. The original Statistical Modeling and Estimation of Reliability Functions for Software (SMERFS) Library was described in the SMERFS Library Access Guide, NSWC TR 84-371. The enhanced library, which now contains 11 models and model applicability analyses, is explained in NSWCDD TR 84-371, Revision 3. The execution of this more powerful library, through the new SMERFS driver, is explained herein.

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